ECONOMIC GEOLOGY

VOL. XXX NOVEMBER, 1935 No. 7

"APLITES" OF HYDROTHERMAL ORIGIN ASSOCIATED WITH CANADIAN COBALT–SILVER ORES.

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INTRODUCTION.

PINK to brick-red rocks—to all appearances of igneous origin—variously termed "aplite," "pegmatite," and "red rock," have long been known to be closely associated with copper-cobalt-nickel-silver mineralization in some of the minor silver-producing camps of Ontario—notably Gowganda and Elk Lake. These two camps were visited by the writer in the summers of 1933 and 1934 in the hope that a close study of the ores and red rocks might show whether the ores were derived from magmas of basic, intermediate or acid composition. The results obtained may not fully answer this question but are of much interest in showing that the "aplite" or "red rock" is not a product of crystallization from a magma but has been formed by the hydrothermal alteration of completely solidified and in places fractured Nipissing diabase. This hydrothermal alteration was the prelude to metal mineralization.

PRIOR INVESTIGATIONS

Canadian geologists[1] as far back as Barlow in 1908 have

[1] Barlow, Alfred E.: The Origin of the Silver of James Township, Montreal River Mining District. Jour. Can. Min. Inst., vol. 11, pp. 256–273, 1908.

Hore, R. E.: Differentiation Products in Quartz Diabase Masses of the Silver Fields of Nipissing, Ontario. ECON. GEOL., vol. 6, pp. 51–59, 1911.

Collins, W. H.: Geology of Gowganda Mining Division. Canada Dept. of Mines, Geol. Survey, Mem. 33, 1913.

Knight, C. W.: Rept. Ontario Bur. Mines, vol. 19, pt. II, p. 163, 1913.

Burrows, A. G.: Gowganda Silver Area. Ontario Dept. Mines, vol. 30, pt. III, p. 21, 1921.

generally recognized the close relations of the "aplite," "pegmatite," or "red rock" to mineralization. To quote Burrows:

> Some veins show aplite next to the diabase, followed by a layer of crystallized quartz, the crystals of which extend into the calcite which may occupy the center of the vein. This type of vein frequently carries some native silver, smaltite and niccolite. . . . The aplite type of vein, however, varies greatly in the arrangement of the constituent parts, the calcite and ores often being irregularly distributed in the aplite.

The "aplites" of the Gowganda and Elk Lake Districts occur as occasional dike- or vein-like masses whose width varies from a mere seam to a foot or two and whose length seldom exceeds a few hundred feet. They have been found only in the Nipissing diabase. Some of the veins, including the most productive, are *not* associated with "aplite," but where "aplite" occurs in dike-like forms its association with the mineralization is so intimate that it must be regarded not merely as paralleling the mineral vein but as constituting an integral part of it.

Although some of the dike-like "aplites" have walls that to the unaided eye appear sharp, others are without sharply defined walls and pass into greenish-gray Nipissing diabase through transition facies that are partly red (Fig. 1). These transitions have been noted by most of the Canadian geologists referred to above.

The dike-like "aplites" have been generally interpreted as true dikes representing the final product of the crystallization of the Nipissing diabase magma.

Red rocks of aplitic appearance occur also in a few localities as *irregular* bodies within the diabase sills at or near their upper contacts. Both Collins and Hore regarded these as products of magmatic differentiation closely similar to the dike-like forms in origin. Bowen,[2] as far back as 1910, regarded the *irregular* masses of red rock in the diabase as well as red phases of the overlying sediments as products of hydrothermal metamorphism by solutions coming from the Nipissing diabase in its final stages of consolidation.

[2] Bowen, N. L.: Diabase and Granophyre of the Gowganda Lake District, Ontario. Jour. of Geol., vol. 18, pp. 658–674, 1910.

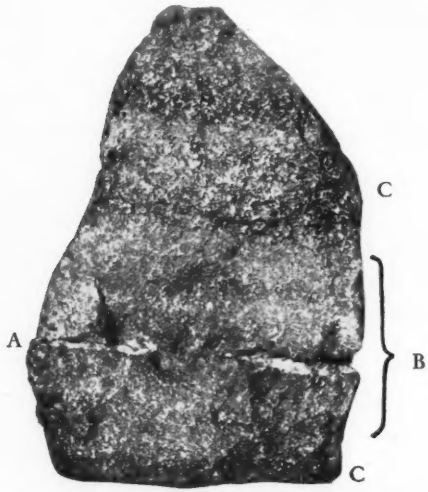

FIG. 1. Calcite vein (*A*) bordered by pink "aplite" (*B*) which grades into mottled green and pink altered Nipissing diabase (*C*). The vein carried nickel and cobalt bloom at intervals. From near Gowganda village. × 1/3.

LESS ALTERED FACIES OF THE NIPISSING DIABASE.

Comparatively fresh facies of the diabase, obtained from the dumps of the Tonopah mine, Gowganda, and the Beaver and Moosehorn mines, Elk Lake, are dark greenish-gray rocks with intersertal texture. The Elk Lake specimens are representative of the more abundant facies in which the laths of feldspar and femic minerals do not exceed 1 to 2 mm. in length. In parts of the Gowganda specimen, however, the same components reach lengths ten times as great.

Microscopic Characters.—None of the specimens is entirely fresh. The original minerals are tabulated in Table 1 and the course of their alteration to secondary minerals is indicated by the arrows.

In the coarsest and freshest rock, parts of the plagioclase laths

are identifiable as labradorite, but elsewhere minute flakes of white mica are developed in them. The dominant ferro-magnesian mineral is augite; it has altered in places to hornblende and biotite, and these in turn, to chlorite. Abundant grains, originally of iron oxide, are opaque throughout and gray in reflected light. They are not, however, homogeneous, for reflected light reveals a grating structure probably indicating an original intergrowth of magnetite and ilmenite. The interspaces are occupied by a graphic intergrowth of quartz and clear, fresh-appearing feldspar lower than balsam in index and showing a grating structure resembling microcline. It is determined as albite because of its optically positive character. Apatite in small needles is a primary accessory associated mainly with the quartz-albite intergrowths. Minute pale-green garnets occur singly or in clusters, almost exclusively in the graphic intergrowths of quartz and albite. This association suggests that they are primary. A few small crystals of titanite, mostly associated with the iron oxides, seem also to be primary.

The two Elk Lake specimens are slightly more altered; no labradorite cores remain; the cores are completely altered to fine mica flakes but the peripheral parts of the crystals are clear albite. There has evidently been a sequence of alteration from the lime-soda feldspar (labradorite) to fine white mica (sericite) and then to albite. The sericite is, however, as shown later, an intermediate replacement product in the alteration of labradorite to albite. Moreover, available analyses of fresh or slightly altered Nipissing diabase all show soda greatly more abundant than potash. It is probable, therefore, that the fine mica is rich in soda, but its isolation for testing is impracticable. The contrast between the clear borders of the feldspars in these specimens and the clouded borders in the less altered diabase is striking.

Thus, even in the fresher facies of the Nipissing diabase, certain alterations are observed that reach their climax in the pink or red facies next to be described and in green diabase bordering some of the mineral veins.

IRREGULAR BODIES OF "RED ROCK" IN THE NIPISSING DIABASE.

In places the greenish-gray least altered phases of the Nipissing Diabase pass by gradations through rocks that are mottled gray and pink into irregular bodies of rock of brick-red color ("red rock"). These gradations were particularly well shown on the dump of the Wigwam mine at Lost Lake, Gowganda District, but were observed also at the Beaver and Moosehorn mines in the Elk Lake District. The transitions are gradual and irregular and without microscopic study would be interpreted as due to crystallization differentiation. Microscopic evidence, however, shows that the red rock has been formed from completely solid normal granophyric diabase through processes of progressive replacement.

Specimens showing the beginnings of alteration to red rock are still gray in general color tone, but the areas between the greenish-gray laths of ferro-magnesian minerals are pink. A listing of the primary minerals and the products of their alteration would be identical with that for Specimens 29 and 37 (Table 1) but the alterations, although qualitatively the same, have advanced farther. The augite has largely altered to green pleochroic hornblende and to biotite, the hornblende in turn is in part altered to pennine and clinochlore, and the biotite to pennine. Original feldspar laths still showing suggestions of carlsbad and albite twinning are now mainly a felt of white mica flakes, but in places the *peripheries* of the feldspar areas are clear albite. It is particularly striking and significant that this peripheral albite is developed only in those parts of the slide where chlorite is abundant, that is, where the alteration of the original ferro-magnesian mineral is most advanced; there also the alteration of the original feldspar has progressed farthest and the mica has begun to alter to the soda feldspar albite with a "clearing up" of the outer portions of the clouded feldspars.

The secondary albite rimming the altered feldspar laths is in places continuous with and in parallel orientation with albite graphically intergrown with quartz in the interstices (Fig. 3).

TABLE I.

SEQUENCE OF MINERAL CHANGES IN HYDROTHERMAL ALTERATION OF NIPISSING DIABASE TO "RED ROCK" AND "APLITE." Arrows indicate the course of the alteration.

Theoretical Unaltered Granophyre Diabase	Least Altered Granophyre Diabase (Spec. 16)	More Altered Granophyre Diabase (Specs. 29, 37)	Gray to Mottled Facies Bordering "Red Rock" or "Aplite" (9a, 27a, 28a)	"Red Rock" of Irregular Bodies (Specs. 4, 7 and 8)	"Aplites" of Dike-like Form (9b, 27b, 28b)
Labradorite	Labradorite → Fine white mica	Fine white mica → Albite	Albite	Albite	Albite
Albite? Quartz } graphic	Albite Quartz } graphic	Albite Quartz } graphic	Albite Quartz } graphic	Albite Quartz } graphic	Albite Quartz } graphic
Augite	Augite → Hornblende and Biotite → Chlorite	Augite → Hornblende and Biotite → Chlorite	Chlorite	Chlorite	Chlorite (sparse)
Titaniferous Magnetite	Titaniferous Magnetite	Titaniferous Magnetite	Titaniferous Magnetite → Leucoxene	Leucoxene	Leucoxene → Titanite
Titanite	Titanite	Titanite	Titanite	Titanite	
Apatite	Apatite	Apatite	Apatite	Apatite	Apatite
Garnet	Garnet	Garnet			
			Calcite	Calcite	Calcite (abundant)
		Pyrite	Pyrite	Pyrite	Pyrite
			Chalcopyrite	Chalcopyrite	Chalcopyrite
			Bornite		Bornite
				Specularite	Specularite

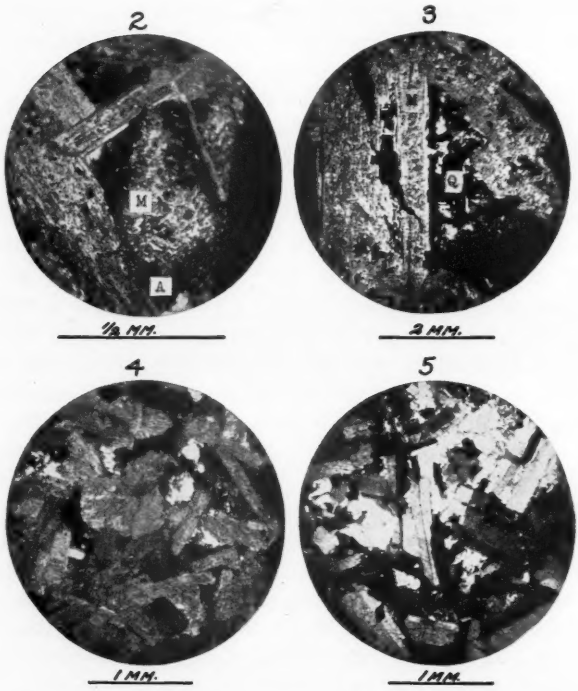

FIG. 2. Mottled pink and green altered Nipissing diabase from dump of Wigwam mine, Lost Lake. A feldspar lath clouded with small flakes of white mica (*M*) has cleared up peripherally by replacement of mica by albite (*A*).

FIG. 3. From same specimen as Fig. 2. In center, albite (white), a replacement of fine white mica, (*M*) is crystallographically continuous with albite graphically intergrown with quartz (*Q*).

FIG. 4. Greenish-gray, somewhat altered, Nipissing diabase from Beaver mine, Elk Lake District, showing diabasic texture. Original labradorite laths are completely clouded with fine flakes of white mica, giving the rock a much altered appearance.

FIG. 5. Pink "aplite" from near Gowganda (Claim T. C. 162), which resulted from the further alteration of rocks, as shown in Fig. 4. Its fresher appearance is due to the replacement of mica-clouded feldspar laths by clear albite. Note the persistence of the diabasic texture.

In the graphic intergrowths of quartz and albite, minute pale green garnets occur singly or in clusters and are probably primary.

Rocks of the sort described above pass gradually into others that are mottled in appearance, with pink areas several centimeters across; little or no augite remains and the alteration of secondary hornblende and biotite to chlorite has progressed farther. Peripheral clearing up of the mica-clouded plagioclase laths, to form albite, has advanced farther and is well shown in Fig. 2. It will be noted that the peripheral albite rims are too irregular to be interpreted as either a preservation or a restoration of original zoning even if other evidence of their development by destruction of white mica were lacking. Chlorite is almost invariably present either within or adjacent to the albite. Scattered grains of pyrite are present, and well within the pink areas nests of quartz and calcite are visible even to the unaided eye.

More advanced stages of alteration in which the red portions dominate notably over the gray still show intersertal diabasic texture defined largely by the laths of ferro-magnesian minerals oriented in all directions. Most of the feldspar laths are now completely freed from mica flakes and are clear albite except for inclusions of chlorite. In reflected light the red color of the albite is seen to be due to minute flakes of hematite, which in a few places are concentrated into tiny veinlets. The relatively large grains of primary titaniferous magnetite persisting through the earlier stages of alteration have begun to alter to leucoxene, and much secondary magnetite has formed as minute automorphic grains scattered through the larger hornblende and chlorite areas. The considerable reorganization implied by this change in the form and distribution of magnetite extends to other components as well, for quartz appears in larger units than hitherto observed, its grains being recognizable even with the hand lens. Calcite has increased in abundance and in places there is considerable pyrite. The calcite has replaced quartz, albite and hornblende, all of which have been irregularly eaten into by it or are penetrated by ragged calcite veinlets.

Facies like those described above pass by transition into others which, viewed in the hand specimen, are pink in general color tone but betray their derivation from the greener facies by the presence of some greenish gray laths of ferro-magnesian minerals and of feldspar diversely oriented. Nests of calcite, quartz and specularite are present; there are occasional quartz veinlets, and chalcopyrite is developed in addition to pyrite. Under the microscope chlorite is found to be the sole ferro-magnesian mineral. Except for the dusting with hematite and the occurrence of some chlorite inclusions, all the feldspar is clear albite. Original titaniferous magnetite grains are largely altered to leucoxene and much of the secondary magnetite intergrown in small grains with chlorite is similarly altered.

In the earlier stages of the alterations that have been traced above, the newly formed minerals in the main were pseudomorphic after the older minerals and the original texture was largely preserved (Figs. 4 and 5); in the later stages of alteration new minerals no longer conform fully to the boundaries of older minerals—calcite and chlorite may replace *several* older minerals and chlorite may assume sheaf-like or spheroidal forms, not controlled by older crystal boundaries. In short, most of the rock, even including the graphic intergrowths of quartz and albite, seems to have been recrystallized; only a few large albite laths and lath-shaped aggregates of chlorite flakes remain as indications of the texture of the parent rock. In general the red rock is so fresh appearing that it would naturally be interpreted as a direct crystallization from a magma were it not for the evidences of progressive mineral transformations that have just been described.

DIKE-LIKE MASSES OF "RED ROCK" IN THE NIPISSING DIABASE.

Although much of the "Red Rock" forms very irregular masses within the normal diabase, as already described, some occurs in dike-like bodies—the so-called "aplite dikes." These are commonly narrow—from a fraction of an inch to several inches—but may be traceable with fairly straight courses for scores of feet.

The walls of some of these " aplite dikes " appear sharp and regular to the unaided eye so that their field characterization as " dikes " is entirely natural. In most cases, however, the walls are neither sharp nor regular and there is a clear gradation from red rock into the greenish-gray diabase walls. These transitions are particularly clear in the coarser grained facies where the change from one rock to the other takes place through a broader zone. It is noteworthy that fine-grained red rock is in general associated with fine-grained diabase, and coarse with coarse-grained.

In some cases a distinctly dike-like mass of red rock in diabase can be traced along its trend into continuity with the red portions of an irregular body of mottled red and green rock. In places small nests of chlorite, quartz, calcite and metallic minerals occur within the aplite; elsewhere small veinlets of these minerals follow the median portion of the " dike." These relations—visible to the unaided eye—all suggest alterations of the diabase proceeding outward from fractures and culminating in mineralization with the metals.

These conclusions from study with the unaided eye are confirmed by microscopic examination. At a locality near Gowganda village, a little prospecting has been done on a minute veinlet along which calcite occurs and, near the surface, cobalt and nickel bloom. For an inch or so on either side of this veinlet occurs red-rock or " aplite " but this passes gradually outward into a mottled pink and green rock in which laths of ferro-magnesian minerals perpetuate an originally intersertal diabasic texture (Fig. 1). The microscope shows that the mottled rock has an intersertal texture closely similar to the unaltered facies of the Nipissing diabase but the feldspar laths instead of being labradorite are clear albite. Chlorite is the only ferro-magnesian mineral. The interstices are occupied by a graphic intergrowth of quartz and albite, the latter often crystallographically continuous with the albite of bordering laths (Fig. 3). What were once grains of titaniferous magnetite with grating structure have been altered to an association of leucoxene and chlorite (Fig. 6).

FIG. 6. "Aplite" from Gowganda (Claim T. C. 162) showing intergrowth of leucoxene (and some titanite) and chlorite, which preserves the grating structure of titaniferous magnetite from whose alteration it was derived.

Calcite is abundant as replacements of most of the earlier minerals. The red rock into which the mottled rock grades carries calcite in much greater abundance and larger masses. Single crystals of calcite form the matrix for many laths of albite. No ferro-magnesian minerals remain. Titanite is apparently a reorganization from the leucoxene of the mottled facies.

Finer grained phases of the "aplite" associated also with equally fine-grained altered diabase occur at the G. W. mine on the east side of Leroy Lake. The dark gray rock there with which the "aplite" is in contact has an ophitic texture defined by laths of albite oriented in all directions and embedded mainly in secondary quartz. Chlorite is the only ferro-magnesian mineral and occurs both as minute inclusions in the albite and in larger areas, many of which are closely associated with altered

magnetite grains. The latter now consist of chlorite, and either leucoxene or titanite or both, but these are intergrown in a grating structure characteristic of titaniferous magnetite. Quartz occurs between the albite laths in grains large enough to embed several of the latter. Calcite is rare. The field relations indicate that this rock is an integral part of the Nipissing diabase sill. The ophitic texture and the abundance of altered magnetite grains testify also to its original diabasic character. The gray rock just described passes into "aplite." The transition, which occurs within a millimeter, appears abrupt to the unaided eye but the microscope reveals complete gradations. All of the minerals of the gray rock are present in the "aplite" but in different proportions and textural relations. Albite instead of being in diversely oriented laths is mainly in larger crystals graphically intergrown with quartz. Chlorite has decreased greatly in abundance and the chlorite-titanite pseudomorphs after titaniferous magnetite have disappeared. Calcite is abundant and grains of chalcopyrite and bornite occur.

The relations of both fine- and medium-grained "aplites" testify, therefore, to (1) a pseudomorphic replacement of the original minerals of the Nipissing diabase to form a rock which, although still greenish gray and of diabasic texture, is composed of albite, quartz, chlorite and leucoxene; and (2) a reorganization of this rock to form a pink or red rock with an obliteration of the diabasic texture, the disappearance of some minerals such as chlorite and the addition of others such as calcite, chalcopyrite and bornite.

ASSOCIATION OF "APLITES" AND "RED ROCKS" WITH METALLIZATION

Only incidental mention has thus far been made of the occurrence of metallic minerals in the red rocks. Not all the red rocks are associated with metallic minerals (with the exception of hematite) and not all the metalliferous veins are associated with red rocks. Where, however, metallization and red rocks do occur together, the relation is so intimate that all observers of

the Gowganda and Elk Lake ore deposits have agreed in regarding the "aplites" as one type of metal-bearing vein—although not the only type.

Although some "aplite dikes"—particularly small ones—may carry no metallic minerals, others carry nests of metallics, quartz, and calcite in their medial portions; in others this portion becomes a well-defined vein whose boundaries against the "aplite" may be either sharp or gradational. Thus, many veins are bounded on both sides by "aplite."[3] In many instances, mineralization with quartz, carbonates, and sulphides persisted beyond the period of "aplite" formation, for veins within "aplite" may send off branches that reach out into greenish-gray facies of the diabase. Among the metallic minerals, hematite and sulphides seem to have been the first to form—first pyrite and hematite, then chalcopyrite and bornite. The sulphides may occur as scattered grains or small aggregates in the "aplite," with or without quartz and calcite, but their principal occurrence is in quartz-calcite veinlets that traverse the aplite. In many "aplite dikes" the mineralization has been exclusively with iron and copper. In other cases, however, niccolite, smaltite and similar minerals, bismuthinite and native silver have formed apparently as a late episode in the same mineralization.

VEINS NOT ASSOCIATED WITH "APLITE DIKES."

Even in the Gowganda and Elk Lake Districts where "red rock" or "aplite" is best developed, not all the veins are associated with "aplite," indeed the larger and more productive ones are not so associated. In the districts of Cobalt and South Lorraine, which in the past have been the most productive, aplites are limited to one known occurrence.

It is of interest, however, to note that the more usual type of cobalt-silver vein, although not bordered by "aplite" is accompanied by notable wall-rock alterations. At the Devila mine,

[3] Some "aplite dikes" poor in metallics carry scattered sheaves of chlorite in their medial portions. Some of these sheaves may be an inch or more in length. Where mineralization has proceeded farther, chlorite is commonly absent.

Elk Lake, vein material on the dumps showed calcite, chalcopyrite, cobaltite, argentite, native silver, and cobalt and nickel bloom. To the unaided eye, the Nipissing diabase adjacent to the vein appears unaltered, but the microscope shows that although the texture is still diabasic the primary minerals have been almost completely replaced. The feldspar laths, originally labradorite, are now albite with a few fine white mica flakes in their inner portions. Chlorite, the only ferro-magnesian mineral, has replaced not only the original ferro-magnesian minerals, but some of the feldspar as well. What were grains of titaniferous magnetite are altered to leucoxene and titanite, but the original grating structure is still preserved. Calcite has developed in great abundance as a replacement of chlorite, albite and quartz. Quartz occurs in the interstices in graphic intergrowth with albite but also in relatively large grains that may enclose several albite laths.

In another specimen from the Devila dump, the alteration has proceeded even farther. The texture is typically diabasic but the feldspar laths are albite with fine white mica flakes in their inner portions. Only a few small patches of chlorite are present; fully half the rock has been replaced by calcite. Grains, once titaniferous magnetite, preserve their original outlines and grating structure but are now mainly leucoxene, titanite and calcite.

At the Moosehorn mine in the Elk Lake District, veins of calcite and nickel and cobalt arsenides are bordered by greenish-gray altered diabase which shows under the microscope a diabasic texture although the original minerals have been completely replaced in a fashion almost identical with that just described for the Devila mine.

To learn whether similar wall-rock alterations characterize the diabase walls in the more productive districts, specimens of Nipissing diabase bordering veins in the Frontier mine at South Lorraine, collected by the writer in 1932, were studied. On the third level of the mine, samples of the diabase were taken immediately adjacent to a 4-inch vein and also 5 inches away from it. For 3/4 to one inch from the vein the wall-rock is somewhat darker than farther away. The specimen 5 inches from the vein

shows under the microscope an intersertal diabasic texture, the interstices being occupied by a graphic intergrowth of quartz and feldspar. The large plagioclase laths are well above balsam in index and identifiable by their maximum extinction angles as labradorite. Many of the plagioclase laths are, however, largely altered to a felt of fine white mica flakes. The dominant ferro-magnesian mineral is augite, largely unaltered. There is a little primary biotite. In the grains originally titaniferous magnetite, the titanium-bearing component has altered to leucoxene with perfect preservation of grating structure. In the rock immediately adjacent to the vein the diabasic texture is still recognizable, although much obscured by the development of calcite which makes up nearly half of the rock. The plagioclase laths, where not replaced by calcite, are albite clear of mica flakes. Abundant chlorite (penninite) is the only ferro-magnesian mineral. The original titaniferous magnetite has altered to an association of titanite and chlorite. The interstices between the feldspar laths are occupied by quartz in graphic intergrowth with albite. Some of the latter is optically continuous with albite of the bordering laths.

On the sixth level of the Frontier mine the Nipissing diabase was sampled immediately adjacent to the Watson vein and a short distance away. The vein here is about 3 feet wide. The diabase away from the vein, when examined microscopically, shows augite—largely unaltered, plagioclase laths—clouded with white mica flakes and no longer determinable, and leucoxene and magnetite intergrown in lattice structure. Next to the vein the feldspars become pink and give the whole rock a pinkish cast. The microscope shows abundant mica flakes in the interiors of most of them but their peripheries are albite. Chlorite is the only ferro-magnesian mineral. Titaniferous magnetite is completely altered to leucoxene.

In the Nipissing mine, fourth level, what were clearly rounded pebbles of granite in the cobalt conglomerate have been altered, bordering a 3-inch vein, to an aggregate of pink calcite and clear albite.

It appears, therefore, that in the main silver-producing areas at Cobalt and South Lorraine, wall-rock alterations bordering the veins are similar in most respects to those observed at Elk Lake and Gowganda, but only in a few places are they accompanied by strong hydrothermal oxidation and the development of red coloration in the diabase, *i.e.*, the formation of "aplite" or "red rock."

GENERAL SEQUENCE IN ALTERATION.

The general sequence of mineral changes in the hydrothermal alteration of granophyre diabase to "aplite" is summarized in tabular form in Table 1. Where the sequence of alteration is clear it is shown by arrows; thus labradorite has altered to fine white mica, and the latter to albite.

The change from labradorite to fine white mica (probably sodic) and thence to albite involves loss of calcium, and part of the calcium of calcite developed late in the alteration may have come from this source.

The change from augite to hornblende and thence to chlorite involves a loss of calcium and of iron. Some of this calcium, like that derived from labradorite, may have been redeposited as calcite in other parts of the area of alteration. Iron was apparently redeposited in ferric form as hematite, mainly in small thin flakes giving the "aplite" its red color, but in part in larger crystals.

Titaniferous magnetite,[4] which from its grating structure is probably an intergrowth of ilmenite and magnetite, was little affected during the early stages of alteration but was broken down in the later stages. The iron of the titaniferous magnetite —in part ferrous—probably went mainly into hematite. The titanium went into leucoxene, which in the final stages of alteration recrystallized into automorphic titanite crystals.

Calcite appeared after the alteration was well advanced, and may replace albite, quartz or chlorite in irregular fashion or may traverse them as replacement veinlets.

[4] Analysis given by Collins, *op. cit.*, p. 70, shows its titaniferous character.

Garnet is present as minute automorphic crystals in the less altered facies. Its exclusive association with the micrographic intergrowths of quartz and albite suggests that it is primary.

Apatite in slender prisms persists unaltered throughout the metamorphic process.

The chemical changes inferred from the changing mineral composition accord with those shown in a series of chemical analyses of diabases and "aplites" quoted by Collins.[5] These analyses reveal clearly the poverty of both diabases and "aplites" in potash and the particular richness of the "aplites" in soda.

ALTERATION OF SEDIMENTS NEXT THE NIPISSING DIABASE.

Shortly east of Lost Lake the road from Gowganda to Elk Lake makes a sharp turn to the south; immediately north of this turn fine-grained sediments of the Cobalt series roof the sill of Nipissing diabase and have been affected in several ways by its intrusion. These sediments commonly show regular and well-defined bedding, but near the contact the diabase is in places filled with a rubble of angular fragments of the sediments oriented in all directions. Along steeply inclined outcrop surfaces, diabase dikes may be observed that are free from fragments below but higher up carry sedimentary fragments along their sides and still higher up are crowded with such fragments. Chilling effects in the diabase are common along the contacts and there are no evidences whatever of assimilation of sedimentary material by the diabase.

The microscope shows one of the less altered phases of the sediments to consist of very fine-grained aggregates of quartz, flakes of white mica, chlorite and magnetite grains. The texture is fragmental, angular fragments with their bedding variously oriented lying in a slightly coarser matrix of generally similar mineral composition. A very few grains of striated feldspar are associated with the quartz of the matrix.

This argillaceous rock, which in the hand specimen is dark purplish in color, has been converted near the diabase contact into

[5] Collins, *op. cit.*, p. 76.

a brick-red rock traversed by delicate bands that are probably bedding. In contrast to the phases farther from the contact, there is no white mica in this rock. Its principal mineral is albite flecked with hematite dust which was probably derived from magnetite. Next in abundance after albite are quartz, pennine and titanite.

It is significant that these undoubted sediments have been converted next the diabase contact into rocks closely resembling the so-called "aplites" within the diabase both in color and in mineral composition. In the sediments these changes are unequivocally the result of thermal solutions.

CONCLUSIONS.

1. The dike-like masses of "aplite" in the Nipissing diabase of the Gowganda and Elk Lake Districts are not true dikes but are zones of hydrothermal alteration following fractures. Evidence of this is found in:

(*a*) Complete transitions, evident to the unaided eye, from greenish-gray diabase into pink "aplite." Commonly these transitions are gradual. A few contacts appear sharp, but the microscope reveals their transitional character.

(*b*) Microscopic evidence of a characteristic sequence of mineral replacements accompanying the change from diabase to "aplite." These are shown in part in Table 1.

(*c*) Preservation in the transitional facies of the intersertal texture characteristic of the unaltered diabase, as shown in Figs. 4 and 5.

(*d*) Preservation in the transitional and the "aplitic" facies of the grating structure of original titaniferous magnetite, even though that mineral may finally be completely substituted by leucoxene and chlorite (Fig. 6).

(*e*) General correspondence in coarseness between the "aplite" and its associated diabase, fine aplite being associated with fine diabase and coarse with coarse.

(*f*) The only ferro-magnesian silicate of the "aplitic" facies is chlorite, a characteristic secondary mineral. Its presence is

inharmonious with the view that the "aplite" was a direct crystallization from a magma.

(*g*) Neither the clouding of the labradorite laths with fine white mica flakes early in the alteration nor the abundant development of calcite—partly in veinlets—late in the alteration are explainable by magmatic differentiation.

2. The *irregular* bodies of "red rock" in the upper portions of Nipissing diabase sills are identical in composition with the dike-like "aplites" and show identical transitions into the diabase. They are regarded as products of irregular hydrothermal alteration of the diabase.

3. Certain pink alterations of well-bedded argillites just above the diabase sill involve mineralogic changes similar to those in the development of "aplite," including the formation of abundant albite, chlorite and hematite. These alterations in the sediments are believed to have been accomplished by solutions of the same type and from the same source as those responsible for the "aplite" and "red rock."

4. The "aplite" and "red rock" are closely associated with metallization, notably with iron and copper, but subordinately with cobalt, nickel, silver and bismuth. The process of development of "aplite" and "red rock" passed without recorded break into metallization.

5. The mineralizing solutions were particularly rich in soda, as shown by the abundant development of fine white mica and albite. In the later stages of mineralization, at least, they carried the sulphur and carbonate radicles in abundance.

6. The thermal solutions that developed "aplite" and "red rock" were oxidizing solutions converting magnetite and ferrous silicates into ferric oxide (hematite).

7. Those veins of Gowganda and Elk Lake that are bordered by green diabase rather than "aplite" show in their walls hydrothermal alterations similar to those involved in the formation of "aplite" except that hematite, and hence a red coloration, is not developed.

8. Re-study of greenish-gray diabase bordering some of the

most productive veins at South Lorraine also reveals the same sorts of hydrothermal alterations.

9. The copper-rich mineralizations associated with the development of "aplites" and the more usual types of cobalt-nickel-silver mineralization are interpreted as related facies in the general hydrothermal mineralization of the region. The former probably took place under somewhat higher temperature conditions than the latter, with notably greater development of hematite as well as copper minerals. Economically it was of relatively little importance.

10. Field and microscopic evidences combine in indicating that the Nipissing diabase sills were not only completely crystallized but also considerably fractured and in places faulted prior to the hydrothermal development of "aplite," "red rock," and ores. It is unlikely, therefore, that the sills themselves were the source of the hydrothermal solutions.

11. It is probable that the hydrothermal solutions came from a deep-lying magmatic source. This may or may not have been the same source from which the Nipissing diabase came. Its composition is also uncertain.

UNIVERSITY OF CHICAGO,
January, 1935.

TRENDS IN PETROLEUM–PRODUCTION PRACTICE.

W. E. WRATHER.[1]

THE PRODUCING branch of the oil industry has undergone radical change in recent years through the application of engineering research to its problems. This paper will outline some of the more important accomplishments in petroleum engineering, which have contributed to improved production practice. A strictly chronological treatment of the subject, although desirable, is difficult for the reason that the development of a new idea and its mechanical adaptation often spreads over a period of years. Innovations are often perfected slowly after a long period of experimentation, and accordingly it is often impossible to assign specific dates to their acceptance. Within the past fifteen years a new profession of petroleum engineering has developed which is increasingly responsible for the initiation of new or modified production practice.

The oil industry in the United States recently celebrated its seventy-fifth anniversary. Throughout the first sixty years of this period the oil producer was content to use substantially the same technique and with slight modification, similar equipment. Late in this sixty-year period, rotary drilling equipment replaced cable tools in certain areas, but the newer method was accepted reluctantly only after a bitter and expensive struggle which resulted in bankruptcy for many of the more obstinate advocates of cable tools. It is typical of this era that change and innovation were resented. Drillers trained in the older Appalachian fields migrated westward, carrying with them a clannish belief in the superiority of their methods and the finality of their judgment. New recruits fell heir to these beliefs, and this conservative mental attitude persisted for fully sixty years. Such me-

[1] Presidential Address, Society of Economic Geologists, New York Meeting, February, 1935.

chanical improvements as were offered from time to time by equipment manufacturers seem seldom to have originated from suggestions made by the operators themselves, but were devised by supply companies to increase sales. Throughout the period, machinery and tools became heavier and more sturdy but basic principles remained substantially unaltered. In the past fifteen years more changes and improvements have been effected in oil production than in the entire preceding sixty years.

It is significant that certain developments were foreshadowed decades before they attained acceptance, as will be demonstrated by the following examples: In 1866 a patent was issued "which clearly discloses the art of rendering liquid the vapors that rise with or are forced up with petroleum."[2] Yet casing-head gasoline prior to 1913 was a negligible increment of total gasoline production in the United States. Nearly fifty years elapsed before this specialized industry became a demonstrated commercial success. Rotary drilling, utilizing the principle of diamond-drill coring, was introduced into Pennsylvania prior to 1865.[3] The idea lay dormant, nevertheless, until in the late nineties when the oil frontier had advanced to Central Texas. The development of Spindletop, discovered in 1901, ushered in the widespread use of rotary tools. A prophecy of the bottom-hole choke lay in the exploit of an ingenious Pennsylvania operator who in 1862 set a wooden plug with a 1½ inch orifice near the bottom of the casing in a producing oil well, thinking thereby to hold the oil in the ground for better prices, as well as to save tankage expense.[4] These illustrations indicate that individual ingenuity was not lacking, but the time was not ripe for the proposed ventures. Gasoline was not a commercial product of early refining; casing-head production awaited the appearance of the automobile; and Pennsylvania was scarcely a suitable field in which to evolve rotary drilling.

[2] Burrell, Geo. A. *et al.*: U. S. Bur. Mines, Bull. 88, p. 10, 1915.

[3] Bone, J. H. A.: Petroleum and Petroleum Wells, p. 42, Phila., 1865. Eaton, S. J. M.: Petroleum; A History of the Oil Regions of Venango County, Pa., p. 125, Phila., 1866.

[4] Henry, J. T.: Early and Later History of Petroleum, p. 288. Phila., 1873.

The most probable reason for the long delay in the development of production engineering in the oil industry is that early methods were ordinarily adequate to supply the market with oil from the rapidly expanding virgin oil regions of the United States, and there seemed to be no need for change. The economic stress of the moment was not sufficiently acute to demand perseverance along these lines.

Some twenty years ago geology was accepted by the industry, and thereafter an improved technique of oil finding may be said to have resulted in the premature discovery of new fields. Deeper sources of supply were indicated by a better understanding of structural geological conditions, and this spurred on the evolution of drilling rigs and equipment capable of drilling to ever-increasing depths. Ultimately, production was so accelerated that lower prices undermined the industry and threatened ruin. Effective proration, introduced in 1926, spread rapidly through the oil regions and gave the production engineer his great opportunity. It became increasingly necessary to devise production methods that would check the flood of oil and at the same time least impair reserves for the future. Out of this situation has evolved a production technique which will now be considered in greater detail.

DEEPER DRILLING.

Every notable increase in well depth has had perhaps equal news value in its day. No doubt the first well to attain a depth of 2,000 feet aroused as much contemporary interest as did the present record depth of 11,377 feet recently attained in a California test.[5] A few illustrations will serve to visualize the accelerating pace of deep drilling. Twenty-five years ago 2,000-foot wells were considered deep and a 3,000-foot producer was of unusual interest. In 1918 the completion by the Hope Gas Company of a 7,386-foot test in Harrison County, West Virginia, was widely heralded as a record for depth. This was

[5] Gulf Production Co., McElroy No. 103, Upton Co., Texas, had reached a depth of 12,468 feet on April 25, 1935. This test is located in the southern portion of the West Texas Permian Basin.

eclipsed the following year by the same company's 7,579-foot test in Marion County, W. Va. In 1928 came the discovery of a prolific oil horizon at 8,500 feet in the Big Lake field of West Texas. The first ten thousand-foot test was completed at Rincon, California, in June, 1931, and in subsequent years eight tests in the United States have exceeded that depth.

The great depths actually attained in most of the very deep recent tests were not contemplated when the wells were started. Especially designed equipment was seldom used. In general the same pipe and drilling equipment were used that would have been employed for depths of 7,000 or 8,000 feet. This points clearly to the importance of the human element. Almost without exception pride in unusual achievement coupled with mechanical ingenuity have conspired to bring about the desired result. Recent improvements in standardization, metallurgy of pipe and connections, and design of machinery were undoubtedly important contributing factors, as were also intelligent foresight and planning. All recent deep tests were drilled with standard rotary tools. Electric power was used exclusively in drilling the deepest test, located in the Belridge field, California. From the foregoing, it is evidently a safe prophecy that even greater depths may be expected at any time.

It is outside the purpose of this discussion to speculate upon how deep oil may be found in the earth's crust. Present knowledge of the physics and chemistry of the hydro-carbons suggests the possibility, even the probability, that crude oil, especially that recoverable from great depths, exists in the sand in a different physical state than when delivered at the surface. Yet despite the influence of greater heat and pressure with increasing depth, it seems a tenable conclusion that suitable source-material entombed and sealed in folded sediments should result in accumulations of recoverable oil at depths greater than have yet been penetrated. If this be true, there are certain areas in the United States, notably in California and the Gulf Coast, where these conditions may be met to depths of 20,000 feet or over. No commercial oil has yet been discovered below 10,000 feet, but if

deeper sources of oil are demonstrated by progressively deeper drilling there seems a reasonable expectation that drilling equipment will be devised to make them available when such high-cost oil can profitably be absorbed by the market.

DRILLING PRACTICE.

Rock Bits.—Some of the more important technological advances that have contributed to the success of deeper drilling may next be considered. In usefulness and adaptability rotary equipment has far outstripped cable tools throughout the more recently developed oil regions. The rotary method was evolved in the region of unconsolidated sediments bordering the Gulf Coast and was at first considered suited only to such areas. Great difficulty was experienced even there in drilling through the occasional hard strata found in the midst of the softest formations. The early fish-tail bit was incapable of cutting the indurated sandstone and pyrite lenses commonly associated with salt domes, and when run on the weak, lap-welded drill pipe then commonly used, numberless twist-offs resulted. One recalls the rather ineffectual efforts to cut through these hard lenses with soft-steel drag bits, using "adamantine" or chilled shot as an abrasive. Not until the introduction of the roller rock bit which first appeared about 1911, were rotary tools able easily and satisfactorily to complete wells even in the Gulf Coast. As soon as these bits were perfected to give reliable service, rotary equipment at once began to encroach on the hard rock provinces previously opened up by cable drilling. Rotary rigs are now widely used throughout the Mid-Continent region.

Collapsible Bits.—The great loss of time in pulling out the drill stem to change bits has been a constant inducement to inventors to produce a collapsible bit which would permit of changing cutters without removal of the drill pipe from the hole. Very deep wells may require as much as eight hours to make the "round trip." No such bits have yet proved a success, but several are now being tested. When and if such a device is perfected it will materially speed up drilling and reduce costs.

Crooked Holes and Directional Drilling.—It has long been realized, especially in cable-tool areas, that holes frequently deviated from the vertical in drilling, and although the resulting crooked holes invariably led to increased operating costs through worn and leaky casings and incessant parting of rod lines, this unsatisfactory situation was accepted philosophically as inevitable. In the development of the Seminole area in Oklahoma, discovered in 1925, the crooked-hole problem was brought sharply into focus. The apparent vagaries in depth of the producing sands in a region which from all available geological information should have been reasonably regular, led to experimentation with acid bottles which clearly demonstrated an alarming condition. Numerous holes showed a deviation which indicated that they might have tapped the sand across property lines on adjoining leases. Steps were promptly taken to insure the drilling of straighter holes, and legal complications were avoided. Crooked holes in rotary-drilled wells are usually due to too great weight bearing down on the bit during drilling. Drillers in their anxiety to make hole commonly rotate the drill too rapidly and allow it to feed downward as rapidly as the bit will cut. It was found that appreciable deviation usually occurred below a thousand feet, in other words, as soon as the length and weight of the drill pipe became great enough to cause the bit to wobble. A weight indicator, attached to the drilling line, was devised which registers on a dial the weight tension on the line. This instrument enables the driller to control the weight resting on the bit and thus regulate the rate of cutting. The perfection of this simple device did more than anything else to cure the crooked-hole problem. At present it is customary to specify in drilling contracts the degree of deviation from the vertical which will be accepted. Crooked holes in both rotary and cable-tool territory are now definitely an avoidable and unnecessary evil.

Out of experimentation with crooked holes has evolved directional drilling, which has been profitably and successfully used in many places. The willful and controlled deflection of a hole toward a specific objective through the use of whipstocks,

knucklejoints and improved methods of well surveying has given added flexibility to rotary tools. The effectiveness and precision of the operation has been amply demonstrated in many localities under diverse conditions. For instance, in the Elwood, California, field, where approximately one-half of the productive area is beneath Pacific Ocean tidewater, deflectional drilling has been used to complete three regular locations from a common base in the 3,200–3,300-foot sand. Durable and expensive foundations are required for tidewater drilling, and multiple drilling through a common surface hole effects a very considerable economy.

Drilling Fluid.—For many years no special attention was paid to the consistency or weight of drilling fluid for rotary holes. Any conveniently located gumbo or clay was used for mud mixing, and only when drilling through a known high-pressure gas sand was the mud thickened or the pump pressure increased. Gas blow-outs, not to mention drill stems stuck by heaving shales or collapsed walls, were all too frequently the inevitable result. In recent years it has been the practice to regulate the weight of drilling mud by the introduction of barytes, hematite, or other heavy minerals, and to secure fluidity through a mixture of tannic acid and sodium hydroxide. The composition of drilling muds, especially in deep tests, is now given careful study to insure proper balance between requisite fluidity and adequate weight. It is recognized that the colloidal properties of mud are largely responsible for the desired properties. Ordinary muds generally weigh from 70 to 85 pounds per cubic foot. This weight may be almost doubled by the introduction of heavy minerals. The opinion is often expressed that one of the most important factors in deep drilling is proper attention to drilling fluid. It may be noted incidentally that a great hindrance to drilling in deep wells in California, where geothermal gradients are apt to be high, has been the drying or dehydration of the circulating drilling mud due either to great heat or to sub-saturation with moisture in the deeper rocks. The drying is thought to be most pronounced opposite sandy formations, and results in hardening the mud until no amount of pressure will induce circulation.

Derricks.—Brief mention should be made of the evolution in derrick construction. Until within the past six or seven years there was a prejudice against the use of steel (pipe or angle-iron) derricks. It was contended that they were too rigid and were apt to collapse when subjected to heavy strain. The older standard equipment was the 72 or 84-foot wooden derrick, designed to handle pipe in trebles or units of three joints. Today demountable bolted steel derricks are almost universally used. Present 122-foot steel structures with 24-foot base, structural steel and concrete foundations, are an advance over the wooden fire hazards of old.

Coring.—There has been a notable change of attitude in recent years with regard to coring. A glaring defect of the early rotary was the frequency with which it drilled through and sealed off productive sands without a sufficient showing of oil to justify a test. All too frequently the driller's log, the only relic of an expensive test, was almost valueless as a source of information. Coring was obviously needed to overcome this deficiency. Early core barrels were crude and ineffective and were used reluctantly. Today there are numerous coring devices for both rotary and cable tools, which are used not only to core suspicious sand but to secure information for geological correlation. In the Gulf Coast, drilling is no longer the haphazard adventure of yore. The average wildcat well yields its measure of information through cores and samples, which is valuable in subsequent regional correlation.

PRODUCTION ENGINEERING.

The foregoing discussion deals only with the technique involved in drilling. Of greater importance even are improvements in methods of recovering the oil from the sand. Until possibly 1920, it was customary to allow flush producing wells to flow substantially to capacity through the casing. When the gas pressure declined until it was incapable of lifting the oil, tubing was inserted and the well was put on the pump. If sufficient gas remained, pumping at first resulted principally in agita-

tion of the fluid, during which period the well was said to be "pumping and flowing." After gas expansion ceased to be a lifting factor, there followed a declining pumping life, ending eventually in abandonment. High-pressure gas was considered a nuisance, though it was vaguely thought to indicate longer-lived and more prolific production. Gas wells were frequently blown wide open into the air in the hope they would "blow into production." The gas was thought unsuited for gasoline extraction until it had declined in volume and increased its vapor content. In earlier days, flush production which could not be absorbed by the market was run to steel or earthen storage, to deteriorate by evaporation and withstand the hazard of destruction by fire. Engineers yet young in years of service recall this easy-going, passive and unvarying procedure.

Then came the day of mounting surpluses and a growing conviction that unless forbearance was exercised, the whole industry faced ruin. Those of the old school stoutly contended that the flush fields should be allowed to flow to capacity and in the briefest possible time remove the menace of overproduction. A newer school contended for proration and ratable taking on an equitable basis. The latter group prevailed and proration must be accepted for better or worse, for the present. Whatever may be its short-comings, it has without doubt forced technical advances of inestimable benefit to the industry.

Equitable proration obviously must be predicated on the relative capacity of wells to produce with due regard to the conservation of expulsive forces in the field. An unexpected potentiality lay in that single phrase "the capacity of a well to produce." The more it was pondered the more complex it appeared. Gradually the conviction deepened that the industry had accumulated throughout the years very little critical data which could be brought to bear on the solution of the problem. Studies of permeability, porosity, well spacing, dissolved gas and its effect upon fluidity, gas-oil ratios, bottom-hole pressures, and many other problems of a related nature, were instituted to supply the needed information. Most of these problems had been attacked

before, but certainly their inter-relations were better appreciated through the new angle of attack.

We may now consider briefly the manner in which these several factors interact and become an integrated problem. A relatively porous medium may be completely saturated with a fluid of such viscosity and adsorptive properties that comparatively little of the fluid content can readily be extracted. A far less porous medium may be saturated with fluid whose viscosity is so reduced by temperature, pressure, and the influence of dissolved gases that it is mobile in the sand and is capable of moving readily through it. Crude oil of the latter class may be easily and more completely extracted. The oil producer is concerned with extraction, more than with a mere knowledge of volumetric content; therefore permeability of a sand is of greater importance to him than mere porosity. A relatively smaller volume of extractable oil in the sand is worth more commercially than a much greater volume of a less extractable product.

When a well taps a permeable oil-bearing formation, a pressure differential is established, and dissolved gas, if present in sufficient quantity, begins to evolve and move entrained oil toward the hole. The expanding gas absorbs heat which slightly reduces the temperature of the oil. In the East Texas field, the oil is under-saturated with gas; therefore gas is probably not at present an expulsive force although it may become a factor when bottom-hole pressures have been reduced to around 750 pounds. With the loss of gas from solution, the solvent capacity of the oil is lessened, and this, coupled with the reduction in temperature and pressure, causes many light-gravity oils to deposit paraffine and related solids in the interstices of the sand adjacent to the hole, or on the inner walls of the tubing. If back-pressure is held on the sand, gas evolves more slowly from solution, it has less tendency to by-pass the oil, and therefore more effectively forces the oil toward the well and lifts it to the surface. The gas being kept longer in solution gives greater fluidity to the oil, retards paraffine deposition and tends toward more complete extraction.

As indicated above, there is scarcely any doubt that the average crude oil delivered into the flow tank differs in many respects from the same oil in its original condition in the sand. This difference is usually proportionate to the depth. Therefore our past deductions, derived primarily from a study of phenomena at the well head, have been misleading. This conclusion has led lately to a study of conditions at the face of the sand in the bottom of the hole. The amount of gas originally dissolved in the oil, as well as the amount of free gas, must be known before a suitable gas-oil ratio can be established. Although permeability is usually considered a function of the reservoir rock, the physical properties of the oil in the sand must be known before the effectiveness of permeability can be correctly determined; and bottom-hole pressures, which are an index to the rate of depletion of the sand, must be known, in order to regulate the uniformity of withdrawal. Flowing bottom-hole pressures at different rates of flow compared with static reservoir pressure also supply an index of comparative permeability. Without a knowledge of permeability of the producing formation and a correct understanding of the physical character of the oil in the reservoir, and the nature and potency of the expulsive forces (whether hydraulic, gaseous, or a combination of the two), it is practically impossible to outline a rational program of well spacing.

Many ingenious devices have been perfected to secure data and control production. Gas-oil ratios are controlled by flowing a well through a reduced aperture, the proper diameter of which is determined experimentally. A flow bean or choke, a steel cylinder milled to the proper dimensions, is inserted either in the flow line at the surface or in the bottom of the tubing. The latter method, while theoretically desirable, is less favored in oil wells because the choke is less accessible if it requires attention. In high-pressure gas wells it has proven the most effective method of preventing freezing of surface connections. Flow beans were first used in California to check the velocity of flow in violent wells and thus prevent destructive erosion of pipe and connections by sand brought up in the fluid from the pay horizon. The same

result, namely, a reduction in the velocity of flow, is accomplished by tapering the tubing downward. Automatic recording bottom-hole pressure bombs, and bottom-hole thiefs for securing samples of oil as it emerges from the sand, have passed the experimental stage and are coming into wider use. An electrical formation tester based on resistivity is proving a most valuable time saver in giving information on permeability. It has also performed very useful service in supplying specific detailed information on the character of those portions of a cored section which have been lost in coring.

Naturally most of the production practices discussed above, having been developed under proration, deal only with the flowing stage of wells. It is generally conceded that an effective control, exercised throughout the flowing life of a pool, will very considerably increase the ultimate recovery. In other words, the natural expulsive forces, if effectively controlled, are capable of delivering at the surface a greater percentage of the oil in the reservoir than has been obtained in the past, and the additional recovery will be obtained at a very considerable saving in lifting cost. At the present time it is difficult to evaluate this increased recovery, which naturally varies in each field. It has been estimated by Suman, from the results of a questionnaire addressed to executives and engineers, that from 30 to 60 per cent of the oil in the reservoir may be obtained under slow and orderly withdrawal designed to utilize most effectively the natural expulsive forces.[6] This percentage range includes pools of all grades of reservoir conditions, from poor to the best. While given only as an opinion, this statement perhaps represents the present best judgment on the question. Estimates of recovery prior to the introduction of production control ranged usually between 15 and 40 per cent, the majority inclining toward the lower figure. Between Suman's estimate and those of an earlier date probably lies a measure of the possible maximum efficiency of present production control.

The flowing stage, during which natural hydraulic and gaseous

[6] Committee of Interstate and Foreign Commerce, Petroleum Investigation, Part 2, p. 1223, Washington, 1934, quoted by Miller and Lindsley.

forces have been largely exhausted, is followed by the salvage stage, which may be taken to include pumping and any of the various stimulative methods designed to wrest additional oil from the sand.

Pumping.—Pumping methods now in use are distinctly a heritage from the past. The method used today is essentially the same which has been used from the beginning, namely, rod lines operating a working barrel set at various depths of fluid submergence. In view of the ever increasing depths of oil wells, it has been a matter of concern in recent years as to how deep such equipment could be economically used. The discovery of oil at 8,500 feet at Big Lake, Texas, and in the deeper horizons of California, came at a time when it was commonly thought oil could never be produced by pumping from depths greater than 5,000 feet. Today wells are being successfully pumped from depths of 7,000 to 8,000 feet. Iron rods long ago supplanted the wooden rods of an earlier day. Improvements in metallurgy, designed to prevent corrosion and crystallization and give greater tensile strength, have been largely responsible for such success as has been attained to date.

There has been of late a growing dissatisfaction with rod-line pumping, which is at best a cumbersome method, wasteful of mechanical power and subject to innumerable mishaps through carelessness or failure of material. Today there are on the market a number of lifting devices, designed to eliminate rod lines. It can scarcely be said that any of these new devices have yet become established practice, though several of them have demonstrated mechanical efficiency. Among the newer types now offered are: a gas-driven, automatically regulated, turbine pump set at the bottom of the tubing; a plunger lift, involving a steel cylinder driven upward by gas lift through a polished-wall tubing, returning to bottom by gravity after discharging its load at the surface; not to mention various other methods of modified gas lift. There seems to be little doubt that out of this stage of experimentation one or more efficient substitutions for rod-line pumping will eventually be evolved.

Future Prospects.

Today the oil industry struggles with problems growing out of overproduction; the prevailing psychology is one of abundance. Approximately one billion barrels of oil are required annually to meet current demand. This consumption has been approached even during the worst depression years. Present reserves in the United States are variously estimated between 10 and 15 billion barrels, with perhaps 12 billion as a fair average. No major pools (a major pool is here classed as one capable of yielding 250,000,000 barrels) have been discovered since East Texas in 1930 and Conroe in 1931. East Texas is estimated to be approximately 25 per cent depleted. For three years it has been apparent to thoughtful observers that new discoveries have replaced perhaps not more than 50 per cent of current withdrawals. The United States is therefore drawing on reserves at the rate of perhaps one-half billion barrels per year more than is being currently replaced by new discoveries. If this situation continues unchanged for two or three years more—and it is admittedly difficult for geologists to suggest areas in which undiscovered major pools are a strong probability—the most serious ills from which the oil industry is at present suffering will be cured without human interference.

Unless present trends are soon altered, it is inevitable that reserves of oil left in the ground in depleted fields will once again become a challenge to the petroleum engineer. Methods of rejuvenation and stimulation of production by artificial means have for many years been locally important, notably water flooding at Bradford, Pa., and pressure restoration by air in Ohio and elsewhere. This movement was on the verge of becoming nationwide when the flood of cheap oil, starting in the Seminole district, almost automatically thrust it aside. Such enterprises have in the main lain dormant now for the past eight or ten years, but of late they are mentioned with increasing frequency.

Acid Treatment.—It is not the purpose of this discussion to go into the merits of the various processes which have been proposed and tried out in the past to salvage oil from depleted fields.

Only one exception will here be cited. During the past three or four years, limestone reservoirs have been effectively treated by the introduction of dilute hydrochloric acid. Ordinarily about 1,000 gallons of a 15 per cent solution is introduced into the well after it has been properly conditioned, and allowed to remain 48 hours under more or less pressure. The acid eats its way into the limestone, opening up minute crevices, which have either become clogged or were never tapped in drilling; and in certain areas where the reservoir is a relatively pure limestone very beneficial results have been obtained. The method is far from uniformly successful, however. Dolomitic limestone reacts slowly, even when treated with a hot solution, and pure limestones react irregularly. Much apparently depends upon the original nature of the porosity.

Practically all methods of stimulating production in depleted fields necessarily involve high costs, and are usually impractical during periods of low crude-oil prices. There is scarcely any doubt however that these old depleted fields, many of them now verging on abandonment, will be made to eke out a very considerable proportion of our requirements of oil when flush fields are incapable of supplying the demand.

4300 Overhill Drive,
Dallas, Texas,
May 11, 1935.

DIKES AND VEINS OF THE ALAMO GOLD DISTRICT, LOWER CALIFORNIA.

ROBERT S. MOEHLMAN.

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INTRODUCTION.

IN THE Alamo gold district, Lower California, numerous basic dikes, of parallel strike and dip, intrude the quartz-diorite country rock. Narrow gold-quartz veins occur in the quartz diorite, but pinch out abruptly in the basic dikes. Although the dikes were formed before mineralization, they were nearly impervious to the vein-forming solutions. Consequently, the solutions moved upward along the vein fractures between the resistant dike plates, at a rather flat angle determined by the intersections of the veins and dikes.

Metallic minerals are sparse, but microscopic examination reveals an interesting pseudomorphism of the iron sulphides. Pyrite and marcasite were formed from pyrrhotite which broke down under supergene attack, and possess a prominent platy structure inherited from the latter. Instead of being the first sulphide to form, pyrite is here the last deposited, preceding only limonite, in which it occurs in "antecedent veinlets." The Alamo occurrence furnishes more data on the question of the stability of the iron sulphides.

The writer studied the geology of the Alamo district during the summer of 1933 for Mr. J. H. A. Williams, president of the

Alamo Gold Syndicate, who has very kindly given permission to publish this paper. Thanks are also due to Mr. S. J. Clausen, manager of the mine, and Mr. A. Chapa, engineer, for their cooperation in the field, to Professors D. H. McLaughlin, L. C. Graton, and E. S. Larsen, for valuable advice and criticism, and to Mr. E. B. Dane, Jr., for assistance in taking the photomicrographs.

GEOLOGY OF THE NORTHERN PENINSULA.

Alamo is 75 miles south of the international boundary, in a geological environment resembling that of the California gold camps (Fig. 1). The northern part of the peninsula of Lower

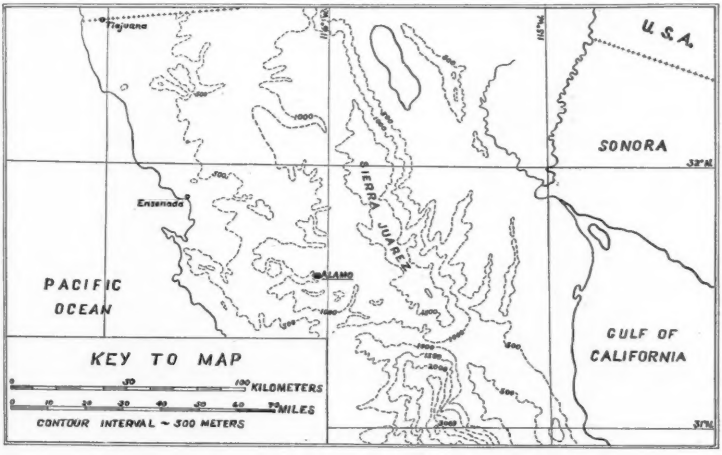


FIG. 1. Northern portion of Lower California, showing Alamo district. (From map issued by American Geographical Society, New York, 1928.)

California is a monoclinal block, tilted westward as a whole.[1] This structure has resulted in a range with precipitous slopes that face the Gulf; an elevation of 10,126 feet is reported by Nelson for the highest peak of the range.[2] The gentler western slope is

[1] Lindgren, W.: Proc. Calif. Acad. Sci., 2, vol. 2, p. 2, 1889. Johnston, I. V.: Proc. Calif. Acad. Sci., 4, vol. 12, p. 952, 1924.

[2] Nelson, E. W.: Nat. Acad. Sci., vol. 16, mem. 1, p. 56, 1921.

maturely dissected, showing many well developed valley floors. Some minor faults break this slope; San Rafael valley between Ensenada and Alamo is apparently a graben.

The core of the peninsula is a batholith, the southward extension of the intrusive masses of southern California and the Sierra Nevada, to which it is similar structurally. The Lower California batholith is made up of many intrusive types, all of which are granodiorite or quartz diorite, but differ markedly in texture and mineralogy. An outstanding feature differing from the southern California batholith is the presence of numerous dikes of gabbro, diorite, dacite and rhyolite.

Roof pendants and inclusions of older metamorphic rocks occur in the batholith and are marginally intruded by the surrounding granodiorite. Northwest of Alamo, near Escondido, is such a body of schist, over four miles in length. On the Gulf side, the "granite" of the range is flanked by crystalline schists.[3]

The intrusions are probably of Jurassic-Cretaceous age. Darton's "general impression" is that most of the "granites" are much older than the Cretaceous.[4] But intrusions continued into Cretaceous time, for Darton notes that an older conglomerate-eruptive sequence of Cretaceous age was intruded before the Chico sediments were deposited. The batholith was certainly pre-Tertiary, for it is capped by Cretaceous (Chico) and Tertiary sedimentary and volcanic rocks. Bluffs of these nearly flat-lying cap rocks front the Pacific coast and occur as remnants on inland plateaus.

SITUATION AND HISTORY OF ALAMO.

Alamo is at the western end of a plain about 20 miles long, which has an elevation of about 3700 feet and drains to the Pacific. This plain, except for an eastern outlet, is hemmed in by four small mountains one to two thousand feet in height.

Placers were discovered at Alamo in 1888, and a rush resulted. Within a year, the outcrop of a rich ore shoot on the Aurora-Princesa vein system was discovered. Lode mines were oper-

[3] Hirschi, H.: Schweiz. Min. u. Pet. Mitt., Bd. VI, p. 349, 1926.

[4] Darton, N. H.: Jour. Geol., vol. 29, p. 725, 1921.

ated by various companies until 1907, after which leases were worked. But all operations ceased in 1912, when the town of Alamo was captured by the "Socialist army," which wrecked the mine and mill. Total production for the district has been estimated at one to two hundred thousand ounces of gold. In the fall of 1932 the Alamo Gold Syndicate entered the district to test its commercial possibilities.

GENERAL GEOLOGY OF ALAMO.

Quartz diorite forms the floor of the valley around Alamo and the hill slopes to the south. Alamo Hill to the west, however, is made up of a distinctive sodaclase granite.[5] Another type of quartz diorite appears to the north. The Alamo quartz diorite is a white, medium-grained, plagioclase and quartz rock with black hornblende and biotite. Streaked inclusions are locally conspicuous. Zoned andesine constitutes 55 per cent of the quartz diorite, and quartz 25 per cent. Orthoclase (5 per cent) is interstitial to plagioclase. Biotite and hornblende are present in about equal amounts, aggregating 15 per cent of the rock. Apatite, zircon, and ilmenite are accessory minerals.

The various basic dikes that intrude the quartz diorite make up one quarter of the area (Fig. 2) They were studied in detail by means of trenches run at 200-foot intervals across the strike. The basic dikes are divided into the older group of coarse gabbro and hornblende porphyry, and younger diabase dikes. A few aplite dikes cut the diabase.

The dikes vary in width from a few inches to forty feet, and the texture varies with the width. Those less than five feet wide are fine to dense, but some ten-foot dikes are coarser than twenty-foot ones. Chill borders are only a few inches wide; in the unchilled portion the grain size is constant across the dike.

The dike rocks, although of different types, show certain min-

[5] The rock is made up of 30 to 35 per cent. perthite, 30 per cent. albite-oligoclase feldspar, 30 per cent. quartz, and 5 to 10 per cent. biotite, thus falling under the head of sodaclase granite as defined by A. Johannsen, in "Descriptive Petrography," vol. 2, p. 110, 1932.

eralogic similarities. Plagioclase is markedly zoned and has a brownish coloring due to nearly submicroscopic inclusions. Two generations of hornblende are apparent: an early brown hornblende occurring in large crystals, and later green uralite. The

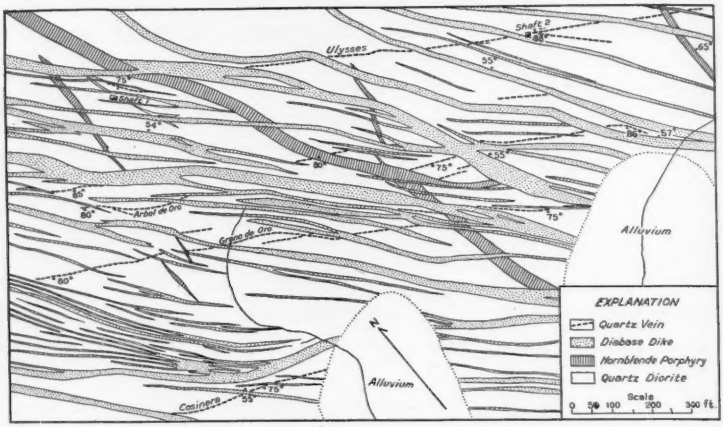


FIG. 2. Basic dikes, western portion of the Alamo gold district.

uralite fibers penetrate plagioclase and earlier hornblende. Biotite is in jumbled aggregates, and is subordinate in amount to hornblende. Some biotite is later than hornblende, replacing it along cleavage planes. Quartz is slightly biaxial. Ilmenite is a common accessory, in skeletal crystals made up of intersecting plates, or tabular forms that follow along hornblende or biotite cleavage planes. Haloes of titanite and rutile generally surround the ilmenite. Epidote has attacked the calcic cores of the zoned plagioclase.

The coarse gabbro type is represented in the mine area by one persistent twenty-five foot dike of north-south strike, just east of the area shown in Fig. 2. Plagioclase, which forms 60 per cent of the rock, is strongly zoned (An 45–75); pericline twins occur. The coarse gabbro is older than the diabasic dikes, but its relation to the hornblende porphyry is uncertain.

The hornblende-porphyry dikes form discontinuous bodies. They pinch, swell, and bend along strike and dip, and have more irregular contacts than the other dikes. Phenocrysts of plagioclase, hornblende, and rarely of quartz, make up 20 per cent or more of the rock. Although hornblende phenocrysts are distinctly subordinate to plagioclase, they are the most diagnostic megascopic component, occurring in prisms from 4 to 10 mm. long.

Microscopic study shows the plagioclase phenocrysts of the hornblende porphyry to be unusual. Apparently, crystallization of the plagioclase was either interrupted or occurred under turbulent conditions. Broken crystals are commonly cemented by a subsequent growth of plagioclase: small plagioclase crystals, variously oriented, may be inclosed within a single plagioclase crystal. From the reaction series, one would expect the later plagioclase to be distinctly more sodic. Actually, there is very little compositional difference between the broken and the cementing plagioclase; both are finely zoned, commonly showing recurrent zones of more calcic composition. These phenocrysts have an average composition of about An 45. In addition to being fractured during growth, the phenocrysts were again fractured shortly before the rock solidified. Some are broken open and filled in by the ground mass of quartz, oligoclase-andesine and biotite. Why this one rock type should have been selected for fracturing is not apparent; some autoclastic mechanism is suggested.

The late diabasic dikes are parallel in strike and dip, averaging N 40° W and dipping 55° NE. Although gabbro, diorite, and dacite dikes are included under this head, they probably represent nearly contemporaneous intrusions. So closely spaced are these dikes that in some cases the same fissure has been used for different upwellings of magma, resulting in composite dikes. Most of the dikes are gabbro, in which plagioclase in the labradorite range makes up 40 to 60 per cent of the rock. Hornblende is the other fundamental constituent; biotite is usually less than 5 per cent. The texture of the gabbro dikes is uralitized diabasic. No original pyroxene crystals inclose plagioclase laths.

Some diorite is associated with gabbro. A gabbro dike was

found to be locally dioritic, containing andesine feldspar, near a small inclusion of quartz diorite. A few of the diabasic dikes are composite, the older member being a typical diabasic gabbro, the other a diorite. A third petrographic subdivision of the younger dikes is dacite. The dacite dikes contain 10 to 15 per cent of quartz interstitial to oligoclase-andesine feldspar. One has a unique outcrop resembling dark cobble stones with light-colored cement. Apparently there were two upwellings of magma, but instead of a single split, resulting in an ordinary composite dike, the first rock was shattered into many fragments and the later magma penetrated all interstices to form a complicated network. Microscopically, the two types are closely similar, except in the salic-femic ratio.

STRUCTURE OF VEINS AND DIKES.

The quartz veins are narrow, averaging less than a foot in width, and occupy parallel fractures with sheared walls. The average strike is N. 60° W., and the dip 80° S. The general trend of a vein zone is well maintained in spite of the pre-vein dikes. In detail, however, the veins bend, pinch or swell, or may fray out into many little stringers. The discontinuous, lenticular nature of a portion of the Ulysses vein is shown in Fig. 3-*A*. A vein may die out completely and pick up again with little or no offset. In some cases the quartz vein proper dies out but a silicified shear zone persists to where quartz again appears (e.g. Ulysses vein).

The quartz veins are younger than all the dikes, but rarely penetrate them for any distance. This does not mean that the vein solutions rose vertically to the dike and there stopped. The solutions flowed continuously along the vein fracture between the dike plates, ascending at an angle of about 25 degrees, determined by the intersection of the dikes and the veins.

In view of the abrupt termination of veins at the dike contacts, some question may be raised as to the older age of the dikes. The belief that they were younger apparently encouraged early fruitless exploration for possible severed vein segments.

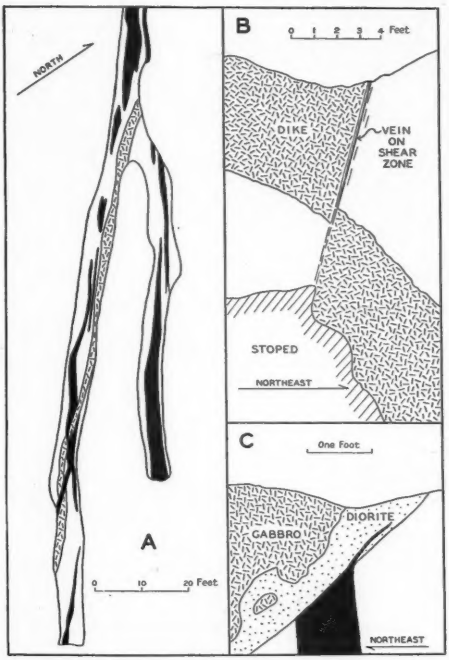


FIG. 3. Veins (black) and dikes (figured) in quartz diorite (white). *A*. Plan of workings on 100-level, southeast from Shaft 2. *B*. Remnant in open cut on Cosinera vein, showing veinlet on shear zone along which dike is displaced. *C*. East wall of prospect pit on Arbol de Oro vein, with offshoot of vein penetrating younger member of a composite dike.

1. Veins penetrate dikes for a short distance, pinching out quickly (Fig. 3–*C*). Although rarely observed on the surface, such evidence may be seen underground. Carbonates and zeolites are relatively more important in the dike-enclosed portions of the vein.

2. Dikes are commonly mineralized near veins with introduced sulphides and quartz. Assays of some mineralized dike rock gave low gold values.

3. In many cases, the veins follow post-dike reverse faults. This is well shown by the Cosinera vein (Fig. 3–*B*).

4. The geometry of vein and dike intersections also indicates an older age for the dikes; the presence of the dikes influenced the formation of the vein fractures. Near dike-contacts, veins generally swing nearly parallel with the dikes. This tendency is not predictable; in places, the formation of a vein fracture has been more influenced by a narrow dike than by a wide one.

If the dikes were younger than the veins and displaced them, perpendicularly, the displacement would be uniform. Assuming such perpendicular displacement and allowing for a 15° deviation in strike and dip, the displacement should be to the left, and proportional in amount to the width of the dike. This is not the case, however. The vein fracture commonly continues straight through the dike, although it has little or no quartz filling. In other cases, the fracture stops at the dike, and on the opposite dike wall begins either to the left or to the right, depending on the response of the quartz diorite to the stress applied between the more competent dike plates.

5. Veins may not match on opposite sides of dikes, indicating that parts on opposite sides were never continuous. A vein may have several branches on one side of a dike or dike zone and be undivided on the other. Such a change in character is particularly likely on opposite sides of a zone of closely spaced dikes.

6. In the Princesa Mine in the eastern part of the Alamo district, ore shoots are said to have raked downward to the southeast at a flat angle, as do the intersections of veins and dikes. Such a rake for the ore shoots is to be expected, if the dikes were older and guided the ore solutions at the time of gold deposition.

ROCK ALTERATION AND GANGUE MINERALS.

All the rocks in the mine area have been somewhat altered. Epidote attacks the calcic cores of plagioclase; titanite develops around ilmenite grains; and biotite and uralite form from the femic minerals. Perhaps this last process is the result of recrystallization with little addition of material other than water.

The principal minerals developed in the narrow zone of altered wall rock near the veins are the same as those found in lesser amounts in the dikes and quartz diorite away from the veins. The same thermal environment probably prevailed during the formation of minerals in both instances, the only difference being the greater introduction of material near the veins.

Close to the vein, plagioclase is attacked by hornblende and biotite, as well as by epidote, and albitization occurs. The minerals occur in clots and irregular bands, each band made up predominantly of one mineral. The altered wall rock is dark brown, blue-green, or yellow-green, due to an abundance of biotite, hornblende or epidote, respectively. The hydrothermal biotite and hornblende are generally fine-grained, and commonly in microscopic clumps. Hornblende may occur in flamboyant groups of relatively large crystals. Epidote is in minute prisms and irregular patches.

The contacts of quartz veins and altered wall rock are sharply defined, but are replacement boundaries. Quartz developed at the expense of orthoclase and unalbitized plagioclase. Replacement "ghosts" can be seen in the veins themselves. In Fig. 4, the original outlines of the plagioclase can be seen preserved as a pseudomorph composed of albite and epidote. The preference of epidote for the plagioclase cores is well illustrated here. Granular intergrowths of quartz and albite occur in or adjacent to the veins.

Biotite plays the part generally taken by sericite, and occurs in the matted habit exhibited by the latter in many ore deposits. Only a minor amount of sericite is present in the veins. The initial attack on plagioclase in the wall rock is by biotite and epidote, rather than by sericite and zoisite. This seems to indicate a higher iron content and perhaps higher temperature for the hydrothermal solutions than is generally the case. Titanite is an erratic constituent of veins and wall rock; in the wall rock, it is in haloes around the ilmenite; in or near the veins, it is in irregular patches or disconnected lines.

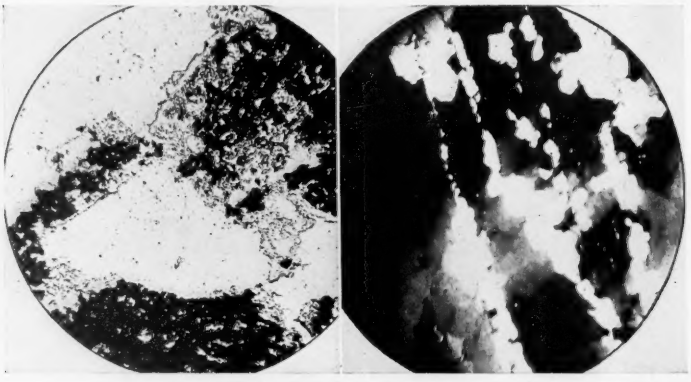
The absence of chlorite and small amounts of sericite and car-

bonate are in marked contrast to the characteristic alteration along the Mother Lode of California.

Zeolites and calcite are distinctly later than the other minerals, and cut across the banded structure. There are at least three zeolites: natrolite, stilbite, and an unidentified platy variety. These late-stage minerals occur in the quartz veins and wall rock, but are insignificant in amount. According to prevailing views of mineral thermometry, the zeolite-calcite mineralization represents much less intense pressure and temperature conditions than the earlier minerals.

THE METALLIC MINERALS.

Two generations of quartz are apparent (Fig. 5). After the quartz vein had attained practically its present width it was cracked, and more quartz, epidote, and hornblende formed along the fractures. The metallic minerals were introduced at this time. The zeolite-calcite mineralization was a still later process.



4 5

FIG. 4. Albite ghost. Rectangular outlines of plagioclase, pseudomorphically preserved in quartz vein by albite; cores are epidotized (black). Specimen taken in vein three inches from wall. × 30.

FIG. 5. Coarse-grained early quartz, showing strain shadows, is cut by parallel stringers of fine-grained later quartz. × 25.

The sparse metallic minerals include galena, sphalerite, pyrite, marcasite, pyrrhotite, chalcopyrite, magnetite, specularite, "limonite," and native gold. Of these, galena, sphalerite, and pyrite are most abundant. Since a good suite of specimens showing sulphides was available from only one vein, the Intermediate, the following statements strictly apply only to this vein, although the relations are believed to be typical of the district.

Pyrrhotite, magnetite, and specularite are earlier than the other metallic minerals. Specularite penetrates magnetite in plates and patches; the plates are criss-cross, perhaps following octahedral planes (Fig. 6), but the mechanism of the oxidation from ferrous to ferric iron is not clear. Pyrrhotite was not seen in contact with the oxides, so its relative age could not be determined.

Sphalerite is later than the pyrrhotite and iron oxides. Specularite plates in magnetite are cut off at the contact of the latter mineral with sphalerite. Corroded remnants of pyrrhotite may be seen in sphalerite. The sphalerite, in turn, is corroded by chalcopyrite and galena.

Gold occurs in areas heavy in metallic minerals, but the exact age of the gold was not determinable. It has been seen in contact with galena, magnetite, and pyrite, but also occurs alone in quartz, free from sulphides.

The Breakdown of Pyrrhotite.—The breakdown of pyrrhotite to marcasite and pyrite, which in turn are oxidized to "limonite," is noteworthy. The pyrrhotite is coarse-grained and shows strong parting, which determined the structure of all the later minerals. Specimens examined were all from one vein at the same horizon, about 150 feet below the present water level; yet it was possible to see all stages in the process from virgin pyrrhotite to "limonite." Differential permeability probably determined where the pyrrhotite would be attacked. Also, small grains completely surrounded by sphalerite were protected.

The first stage in the process was the development of fine grains of marcasite and pyrite along the parting cracks in the pyrrhotite (Fig. 7). Remnants of pyrrhotite intergrown with fine marcasite grains remain in streaks (Fig. 8). Under crossed nicols,

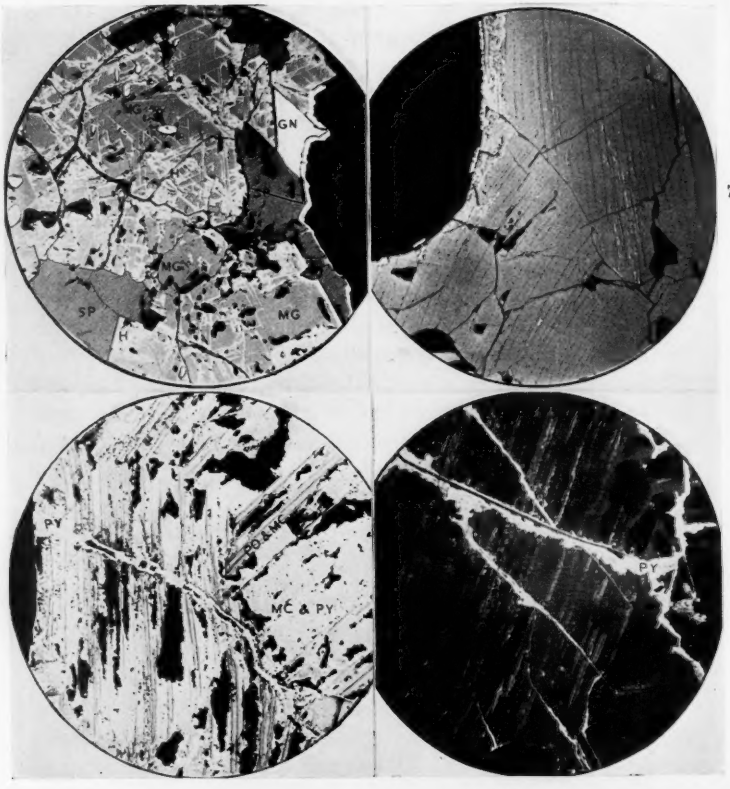


FIG. 6. Specularite invading magnetite, probably along octahedral planes. Sphalerite and galena surround and corrode them. Late pyrite separates metallic minerals from gangue. × 100.

FIG. 7. Incipient attack on pyrrhotite by marcasite and pyrite in fine grains along its cleavage. × 50.

FIG. 8. Late pyrite cutting earlier pyrite and marcasite pseudomorph in bright veinlets. Fuzzy gray areas are fine intergrowths of pyrrhotite and marcasite, with "limonite" in cracks. Large light areas are pyrite and marcasite, the latter being abundant near pyrrhotite residuals. Black areas are "limonite" and bakelite impregnation. × 34.

FIG. 9. Antecedent veinlets of pyrite in limonite, actually earlier than surrounding limonite; gray parallel streaks are fine grains of pyrite and marcasite. × 44.

the pyrrhotite in such streaks shows parallel extinction, retaining the orientation of the original grain as shown by the cleavage, but the marcasite grains are diversely oriented. In cracks between the gray streaks of pyrrhotite and marcasite, " limonite " may be present. Marcasite predominates over pyrite in the fine grains close to residual pyrrhotite. Where no pyrrhotite remains, the iron sulphide is coarser and dominantly pyrite, suggesting that some marcasite may have been converted to pyrite, the more stable form.

When the pyrrhotite was altered, some iron went into solution and was reprecipitated in part as the more stable sulphide pyrite, in hair-fine veinlets that cut all the other sulphides, including the earlier pyrite and marcasite (Fig. 8). The late pyrite veinlets are brighter yellow in color than the earlier pyrite and marcasite. Delicate pyrite veinlets outline the grains of metallic and gangue minerals.

The final phase of the breakdown was oxidation, represented in Fig. 9, where " limonite " has replaced most of the iron sulphide. " Limonite " formed first from the pyrrhotite-marcasite residuals and along the boundaries between gangue and metallic minerals. Some of it fills open spaces formed during the destruction of the pyrrhotite. Apparently the late bright pyrite was more resistant to oxidation than the earlier iron sulphides and, although it actually formed before the " limonite," remains as " antecedent " veinlets in it.

The identification of the iron oxide was definitely established. It is hard, anisotropic, slightly more blue than sphalerite, and shows very weak brown internal reflection. Microchemical tests showed only iron. A spectrographic analysis was kindly made by Mr. G. A. Harcourt in the Harvard Laboratory of Mining Geology; iron was the only metallic element present. Associated with the " limonite " are a few specks of light, hard, anisotropic mineral, considered to be the anhydrous oxide, hematite.

It is probable that acid attack caused the breakdown of pyrrhotite, which is one of the sulphides most susceptible to sulphuric acid. Experiments at the Geophysical Laboratory have indicated

that whereas marcasite forms only in acid solutions, pyrite forms in alkaline solutions or with marcasite in acid solutions. Pure marcasite was obtained from a hydrogen sulphide solution containing 1 per cent free sulphuric acid at 100° C. With lower acidity or higher temperature, some pyrite formed with the marcasite.[6] The findings obtained in the laboratory have been somewhat modified by members of the Geophysical Laboratory as a result of their field observations. At Katmai, marcasite was found deposited by boiling springs, and at Mount Lassen pure pyrite with no marcasite crystallized from acid waters.[7] To summarize, pyrite can form from acid or alkaline solutions; marcasite is limited to acid solutions which may be either hot or cold.

Conclusions of other workers vary. Gilbert described a breakdown of pyrrhotite to marcasite at Ducktown, which he attributed to attack by supergene acid solutions.[8] Newhouse has expressed doubt that acidity is a necessary characteristic of solutions depositing marcasite; he believes marcasite may be deposited by hot, ascending solutions which are nearly neutral.[9] Turneaure considers the marcasite in the Bolivian tin deposits to have been deposited by hypogene acid solutions.[10] At Alamo, in view of the associated "limonite," it is believed that supergene acid solutions deposited the marcasite and pyrite.

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Feb. 19, 1935.

[6] Allen, E. T., et. al.: Amer. Jour. Sci. (4) vol. 33, pp. 169–236, 1912.
[7] Day, A. L., and Allen, E. T.: Carnegie Inst. Pub. 360, p. 138, 1925.
[8] Gilbert, G.: Trans. Amer. Inst. Min. Eng., vol. 70, pp. 998–1023, 1924.
[9] Newhouse, W. H.: ECON. GEOL., vol. 20, pp. 54–66, 1925.
[10] Turneaure, F. S., ECON. GEOL., vol. 30, p. 183, 1935.

PYROMETASOMATIC VEIN DEPOSITS AT TEPEZALA, AGUASCALIENTES, MEXICO.

ALFRED WANDKE AND THOMAS G. MOORE.

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INTRODUCTION.

THE mineral district of Tepezala is situated in a small mountain range in the northeastern portion of the state of Aguascalientes in the Republic of Mexico. A private branch railroad connects the chief mines of the district with the main line of the National Railways of Mexico at the small town of Cobre, some seventeen kilometers to the west and at an elevation of two thousand three hundred meters. Although in the tropics, the district enjoys the

pleasant, spring-like climate of the Central Plateau of Mexico, with only occasional frosts in the higher altitudes during the winter months.

This district, like most other important mining districts in Mexico, was actively mined by the Spaniards two or three centuries ago. When the patio process for treating the bonanza silver ores of Central Mexico was at its height in the eighteenth and nineteenth centuries, the locality was mined for copper sulphate, essential for this process. But activity ceased with the decline of silver mining during the latter half of the nineteenth century and, as in numerous other districts, the mines lay dormant until the closing decade of the nineteenth century.

In 1894 the various mining claims were obtained and consolidated by Guggenheim Brothers. The mines were placed in good working order and a steady production of copper was maintained for over twenty years, during which period probably a million and a half tons of ore was sent to the smelter. Expanding activities elsewhere by the owners, failure to find expected ore at a depth of 175 meters, and the Madero Revolution in 1910, occasioned declining production; operations had practically ceased by 1914 and were only temporarily stimulated by the higher price of copper during the World War. In 1925 one of the former superintendents, encouraged by an improvement in copper prices, endeavored to work the property on a lease, but in 1926 operations again ceased. About 1927 Mr. Henry Wyman, a mining operator of considerable experience in Mexican fields, obtained a lease on the property, intending to treat the dumps and fills, which totalled more than two million tons, and by profits thus gained give the mine some much needed exploration. He formed the Union Copper Company and erected a 600-ton flotation mill which was in full operation by July of 1930, but the drop in the price of copper, just as good operating results were being obtained, caused the temporary cessation of operations in August, 1931.

The senior writer became interested in this property in March, 1931. Through the courtesy of Mr. Wyman, several enjoyable days were spent studying the surface and the various underground

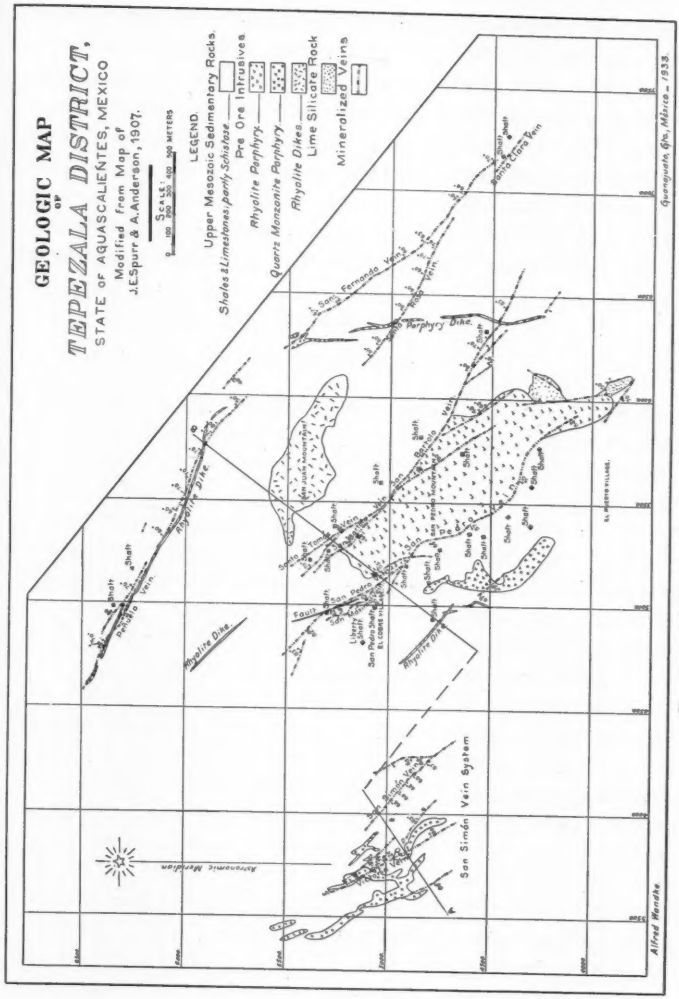


FIG. 1. Geologic Map of Tepezala District.

workings. Thanks to the detailed maps made by J. E. Spurr and to his painstaking and lucid report on the district in 1907, this study was rapidly carried out. The conditions of ore occurrence are of such interest as to warrant description. A selected suite of specimens was studied in the Laboratory of Mining Geology at Harvard by the junior author; on that study the details of the mineral associations are largely based.

Grateful acknowledgment is made to Professors L. C. Graton and D. H. McLaughlin for critical reading of a preliminary draft of this paper and for stimulating suggestions they have offered.

GENERAL GEOLOGY.

Rock Types.

In general, the rock formations over large areas of the Central Plateau of Mexico are relatively simple, consisting chiefly of Tertiary andesite and rhyolite flows as well as their brecciated equivalents. It is in these effusives that the vein deposits chiefly occur. At Tepezala, however, the volcanic flows have been eroded to expose calcareous sediments of Mesozoic age, in which the largest ore bodies are found. In this respect the district resembles Guanajuato and Pozos in the state of Guanajuato; El Oro in Michoacan; Catorce in San Luis Potosi; and Fresnillo, Somberete, Noria de Los Angeles and Pinos in Zacatecas.

Sedimentary Rocks.—In Mesozoic time, probably during the Triassic and Cretaceous periods, a large portion of central Mexico received marine deposits which later were elevated and folded by orogenic movements. In the Tepezala district the oldest exposed rocks are rather pure, slightly recrystallized limestones which rest on a shaly and slightly schistose horizon. Both of these formations have been folded and somewhat metamorphosed. They are considered Upper Mesozoic in age, largely because of their proximity and lithographic similarity to undoubted Upper Mesozoic[1] identified in the near-by state of Zacatecas. Their thickness can only be estimated, since the exposures do not yield measurable sections.

[1] A number of ammonite fragments were found in these limestones.

Effusive Rocks.—In Tertiary time the Plateau section of Mexico, as well as other western cordilleran areas, experienced vulcanism which, initiated in late Mesozoic or early Tertiary time, has not yet become entirely quiescent. Tepezala appears to have been a locus of this activity even though the flows did not accumulate in such great volume as in other parts of the Central Plateau. Although the lavas have been eroded from the immediate vicinity, the dips of the surrounding flows show that this entire district was at one time covered by andesites and rhyolites and their fragmental equivalents. It appears that as the effusives accumulated, the region also underwent a slight doming which in turn produced gentle folds in the volcanic series. For this section of Mexico it is probable that vulcanism was completed by the close of mid-Tertiary time.

Intrusive Rocks.—The chief igneous rocks of the immediate vicinity of the mines are the resistant intrusive stocks that form the conspicuous peaks of San Pedro and San Juan mountains. The San Juan stock measures 200 by 600 meters in exposed area and the San Pedro 400 by 1500 meters.

The San Pedro igneous rock is a fairly fine-grained rhyolite with phenocrysts of quartz and orthoclase. Numerous surface exposures, as well as underground crosscuts that pass from limestone into rhyolite, show clear cross-cutting features that establish its intrusive nature. In the neighborhood of certain shear zones, the rock has a slightly schistose appearance. The abundant and excellent exposures of the contact with the invaded sedimentary rocks display little or no metamorphism. The only visible change in such places is an increased crumpling of the sedimentary rocks, particularly the more shaly layers. The contact dips slightly outward on the northeast and the southwest sides; the shape of the body is thus rather unusual.

The San Juan intrusive is also a rhyolite porphyry but is decidedly more porphyritic than that of San Pedro Mountain. It has a microcrystalline ground mass enclosing good-sized phenocrysts of quartz and orthoclase. Spurr suggests that the San Juan intrusive is the younger and may be post-ore. A more prob-

able assumption, however, is that all the igneous rocks of the district are pre-ore, since several veins cut dike-like bodies resembling the San Juan porphyry. Columnar jointing is exposed in a 50-meter cliff at the northern end of the stock; the six-sided prisms measure about 40 centimeters in diameter and have an exposed length of one to one and a half meters.

There are also in the immediate vicinity other smaller intrusive masses which are dike-like in habit or resemble the irregular, elongated tongues so commonly associated with ore deposits in other districts. Most of these bodies parallel the axes of the larger masses, although one large tongue has a north-south strike. Some of them are composed of fine-grained rhyolite; others are distinctly porphyritic. Still others are slightly more basic and have been classed as monzonite; the largest of these monzonite masses occurs just to the southwest of the San Pedro stock.

The intrusive rocks were most probably emplaced by their magma bodily thrusting aside the enclosing rocks. The field relations of the dikes indicate this; likewise, the marked crumpling of the sedimentary wall rocks about the larger intrusives.

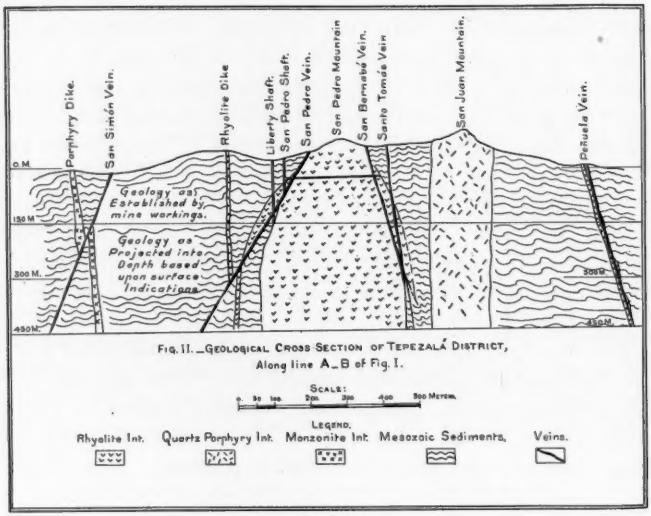


FIG. 2.

Structure.

The structure of the district is relatively simple. The sedimentary rocks have been gently folded and the more shaly members distinctly crumpled. Faulting has affected both the sedimentary and the intrusive rocks.

Although, as previously mentioned, the effusive rocks do not occur in the immediate vicinity, it has been established that the district is the central part of an extended but slightly elevated dome. The doming evidently may be referred to the middle Tertiary and the period of the intrusion. The main period of the folding came, however, at the close of the Cretaceous. Tension set up after intrusion on either side of the San Pedro stock was relieved by a series of northwest-striking normal faults which are parallel to and concentrated at its margins. These faults are not simple breaks, but, because of the irregular settling of the rock masses involved, are complicated by minor branch fractures. The strike varies from N. 50° W. for some of the minor fractures to N. 30° W. for the main fractures. The faults on the southwest of the San Pedro Mountain intrusive dip southwesterly and those on the northeast side dip northeasterly. Lateral portions of the stock have been dropped a distance of almost 100 meters. Inasmuch as some of these faults, which were later mineralized, pass directly into and through portions of the intrusive, it is certain that the period of faulting is later than that of the intrusion. The faulting, as well as the period of ore deposition, may be assigned to the mid-Tertiary. Since that time the area has undergone continuous erosion, which has produced the rugged mountain peaks, exposed the ore zones, and facilitated the deciphering of the geology.

ORE DEPOSITS.

Veins.

General Vein Characteristics.—The ore bodies given chief attention during the examination are parallel northwest-striking vein systems lying respectively at the northeast and southwest contacts of the San Pedro Mountain intrusive and 250 to 400 meters apart. The veins follow the contact of the intrusive for

considerable distances, but at both ends branches pass either into the intrusive or into the sediments. On the southwest side of the mountain the veins dip from fifty to seventy degrees southwest; on the northeast side from seventy to eighty degrees northeast. The main veins, known respectively as the San Pedro and the San Bartolo, have prominent outcrops which can be traced for a distance of almost two kilometers with only minor variations in strike. These strong, persistent fractures are complicated by less important branches, mostly of steeper dip, which diverge at small angles from both the foot and the hanging walls. The hanging wall side of a given main fault invariably shows the greater number of minor fractures. The net result is a much broken, pervious channel-way at the junction of these minor breaks and the main fracture. In part the veins have well pronounced foot- and hanging walls and banded fillings; in part the footwall only is clearly defined, the hanging-wall side for a variable distance being a jumble of altered rock fragments cemented by sulphide ore; or else, the vein consists of many prominent fractures of variable length containing massive sulphide with intervening sheets or lenses of altered rock. Several minor breaks occur at a considerable distance from the main breaks.

Width and Copper Content.—The San Pedro is the stronger of the two main veins. It has a minimum width of approximately three meters and attains a maximum width of seven meters over distances of two or three hundred meters. The ore reaches two per cent copper over the maximum width. By sorting, an average smelter return in excess of three per cent copper was obtained for several hundred thousand tons of ore. The San Maximo vein, the only branch of the San Pedro that has been explored, shows good values over a width of one or two meters. It carries much massive chalcopyrite so that certain portions of the vein as a whole will average ten per cent copper. Sphalerite is somewhat more abundant than usual in this vein, and locally, over short stretches, pockets of solid sphalerite and galena occur.

The San Bartolo vein is rarely over two meters wide, although at a depth of 100 meters it is from four to five meters wide for a distance of two hundred meters. In its narrow branch veins cop-

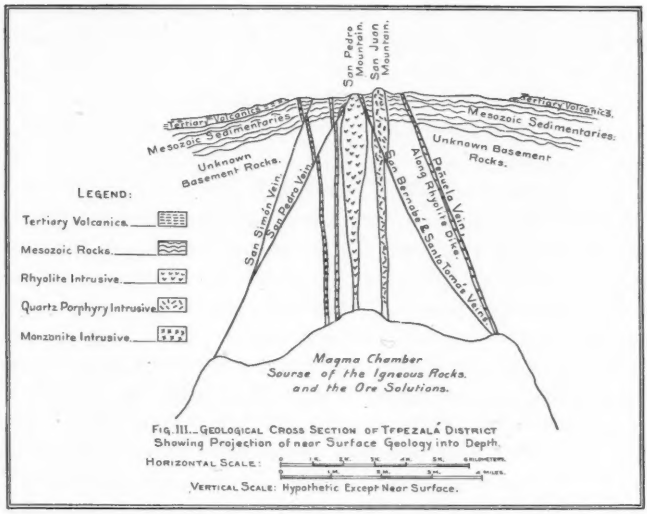


FIG. III.—GEOLOGICAL CROSS SECTION OF TEPEZALÁ DISTRICT
Showing Projection of near Surface Geology into Depth.

FIG. 3.

per values of about seven per cent over a width of approximately one meter are common. The numerous branch veins at the northwest end of the San Bartolo vein, of which the Santo Tomas is the most important, contain twelve or fifteen per cent copper over half-meter widths.

It appears that the narrower the veins are, the richer they are in their copper content. The values as a rule do not fade out toward the somewhat indefinite hanging-wall side but terminate abruptly against a slip or fracture. This is especially true of the wide portions of the ore. In both main veins pyrite is scarce, but the San Bartolo vein carries distinctly more than does the San Pedro.

Malachite and chalcocite are as a rule confined to a shallow zone of oxidation and secondary enrichment. In places, however, chalcocite extends to a depth of fifty or sixty meters, as at the northwest end of the San Maximo vein; and malachite, although rarely exceeding a depth of twenty meters, may form wide zones of one per cent copper ore, as in near-surface portions of the San Pedro vein.

Silver Content.—These veins also carry fifty grams of silver per ton to each per cent of copper. This relation holds rather uniformly for the whole deposit, with no apparent change with depth. A very similar silver-copper ratio was reported by Spurr for the Velardeña district and the Dolores mine at Matehuala.

The Lime-silicate Zone.

Lime-silicate minerals occur both as products of wall-rock alteration along the veins and as gangue minerals in the veins proper.

The altered wall rock, brownish-green or greenish-black in color, is composed of an intimate intergrowth of fine-grained diopside, hedenbergite, epidote and quartz. It forms a definite zone on either side of the major vein systems, attaining a width of fifty meters or even more at certain places in the limestone. This alteration affects both limestone and rhyolite, though the latter is appreciably less susceptible. Where alteration has not been complete, calcite and fine-grained quartz respectively occur as residuals of the original wall rock.

The San Pedro vein system shows the heaviest and widest silicate zone; that of the San Bartolo vein is less pronounced, though always present. Along the San Maximo vein strong marginal alteration grows weaker towards the northwest, as the vein departs farther from the intrusive, so that at 150 meters from the intrusive the vein, though itself containing lime silicate gangue, has sharply defined walls of unaltered limestone.

As later emphasized, the lime-silicate zone is not contact-metamorphic in the strict sense of the word. It is not localized by intrusive contacts of the igneous bodies; as mentioned above, the abundant and excellent exposures of the contact where unaffected by faulting show little or no metamorphism. Although the ore deposits contain some of the usual minerals of contact-metamorphic deposits, they occur along distinct fissures.

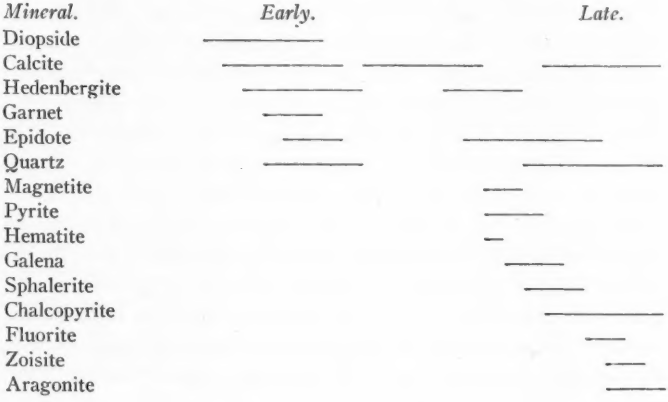
Gangue and Sulphide Minerals.

The sulphide ore, chiefly chalcopyrite with minor amounts of pyrite, sphalerite and galena, is associated with the following

interesting association of gangue minerals; diopside, hedenbergite, garnet, epidote, zoisite, actinolite, fluorite, quartz, aragonite, calcite, chlorite.

Texture.—One of the characteristics of both the ore and gangue minerals is their coarseness of grain. The chalcopyrite occurs in masses a meter or more across, and single crystal faces attain dimensions of two centimeters. Coarseness in the gangue minerals is particularly well exemplified by the acicular or bladed crystals of hedenbergite, many of which are four or five centimeters long and one centimeter across. The significance of this coarseness in relation to the persistence in depth of the deposit is not apparent. It may become highly important if future mining gives some clue to the persistence of deposits characterized by coarse mineral aggregates. At present the lowest workings are at the relatively shallow depth of two hundred meters and it is the opinion of the senior writer that the mines in the Tepezala district are not yet bottomed.

Sequence.—The mineral sequence is most clearly expressed in tabular form. The sequence shown is generalized; departures from it and even reversals occur. On either side of the San Pedro Mountain intrusive, and particularly along its northeast side, the order of deposition is approximately as shown below.



On the southwest side of the mountain the order also holds for the greater portion of the San Pedro vein, but toward the northwest, where it extends well into the limestone, the chief mineral developed is coarse-grained diopside, which is replaced by coarse calcite, and this in turn by quartz. It appears that even though the tendency was for the limestone to be replaced by a silicate, there was, nevertheless, an upset in the equilibrium which permitted the deposition of calcite. In this section hedenbergite is only sparingly developed, although characteristic of other parts of the deposit. Here, too, garnet becomes less and less abundant towards the northwest.

In the northwest or Tiro Azul section of the San Pedro mine the San Maximo vein was also examined. Its chief gangue mineral for the horizon examined is pale grossularite garnet, with which the later chalcopyrite is intimately intergrown; hedenbergite and epidote are scarce. Diopside, a common and abundant mineral along the main vein, is sparse, perhaps because it has been replaced by garnet and the sulphides.

A somewhat earlier stage than the one just described is found in the Venturita section of the main vein lying just northwest of Tiro Azul. Here the earliest and commonly the chief gangue mineral is rather coarse-grained diopside. The sulphides replace the diopside directly, apparently without the intermediate development of abundant hedenbergite and epidote which is invariably found to the southeast. Hedenbergite and epidote occur only sparingly; fluorite, later than the sulphides, is rather common and yields in turn to quartz, which is the latest of the gangue minerals. Fluorite appears to be a common and persistent mineral, although not necessarily abundant, in many mines of the Central Plateau, particularly those containing the base sulphides.

At Tepezala, as in many of the Tertiary gold and silver deposits, early calcite is replaced, commonly pseudomorphically, by quartz. In some places an external coating of pseudomorphic quartz is present; in others the quartz completely replaces the calcite. The deposition of ore minerals appears in most cases to follow this particular stage. It might be argued that the lime-

stone walls at Tepezala influenced the development of this early calcite, but since it occurs over and over again in other deposits where the vein walls are igneous rocks for several thousand feet along the dip, it appears that this is not the only explanation. It is probable that calcium carbonate, abundant in the early phase of the ore-bearing solutions, gives way to increasing amounts of silica, which replaces the calcite previously deposited and transports it nearer to the surface. It seems reasonable to suppose that the various constituents of great volumes of rock dissolved by ascending ore-bearing solutions will in some way influence the composition of the minerals that are later deposited, but in many instances the precipitated minerals are entirely different from those of the rocks in which the ore deposits occur.

The various stages of deposition may be summarized as follows: The first solutions to rise followed closely the throughgoing, deep-reaching fracturing and produced an intensive and extensive lime-silicate zone along both sides of the fissures in both limestone and intrusive rocks. During this first stage were developed diopside, hedenbergite, garnet, epidote, calcite and quartz. Later the solutions carried the various sulphide minerals, chiefly chalcopyrite, in addition to those of the first stage. In the lime-silicate zone the chalcopyrite is found replacing coarse hedenbergite with which are associated epidote and quartz. As the second or sulphide stage came to an end, fluorite, zoisite, quartz, aragonite, calcite, actinolite, and uralite were developed.

It appears that the Tepezala district supports the suggestion of Spurr [2] that the sulphides follow closely the alumina- and silica-bearing minerals. Such a sequence is probably particularly true of deposits containing abundant base metals.

Comparison of Pyrometasomatic Districts.—It is of interest to consider the similarities which exist among certain of the Mexican pyrometasomatic districts. These districts have a somewhat similar geological setting and show by their mineral suites that

[2] J. E. Spurr. The Ore Magmas, 1st edition, 1923, pp. 624 and 643. McGraw-Hill Book Co.

solutions rising from deep in the earth's crust under similar temperatures and pressures into widely separated areas produce similar deposits. The minerals are listed in the order of deposition:

Matehuala.	*Velardeña.*	*Tepezala.*
Aluminous Pyroxene	Pale Garnet	Diopside
Aluminous Garnet	Hedenbergite	Calcite
Vesuvianite	Epidote	Hedenbergite
Wollastonite	Quartz	Grossularite Garnet
Hedenbergite	Apatite	Epidote
Andradite	Sulphides	Quartz
Quartz	Orthoclase	Magnetite
Adularia	Actinolite	Hematite
Sulphides		Galena
Fluorite		Sphalerite
Actinolite		Chalcopyrite
Calcite		Fluorite
		Zoisite
		Aragonite
		Quartz
		Calcite

In these deposits the occurrence of the mineral hedenbergite may have some significance in indicating the relative temperature at the time the deposits were formed. In a recent paper, Bowen, Shairer and Posnjak [3] state:

> Solid solution series are found of both orthosilicate and metasilicate composition. The latter are of particular interest inasmuch as there are two series. The one is stable at low temperatures and is of the hedenbergite type. The other is stable at high temperatures and is of the wollastonite type. Full evidence of the continuous variation of the optical properties, lattice spacing, and thermodynamic properties of the solid-solution series is available. The fact that hedenbergite is a low-temperature phase is of significance in connection with its natural occurrence.

Classification of the Deposits.

On the basis of form, the Tepezala ore bodies are vein deposits. On the basis of mineral association they are what are usually

[3] N. L. Bowen, J. F. Shairer and E. Posnjak. System CaO–FeO–SiO_2, Bulletin Geological Society of America, vol. 44, 1933, pt. 1, p. 74 (abstract).

called high-temperature pyrometasomatic deposits. The ore deposits are closely related to stocks, and the setting at first appears to favor the hypothesis that the ore solutions were derived from the adjacent igneous bodies and thus to lead to their classification as of the usual contact-metamorphic or pyrometasomatic type. The pyrometasomatic deposits are described by Lindgren [4] as follows:

> The form of such deposits is irregular and bunchy, but many of them are tabular by reason of following the contact, or certain strata in the intruded rocks favorable for their deposition. Their mode of occurrence is metasomatic,—that is, they are formed by replacement of the enclosing rock with addition of substance. They are formed at high temperature by emanations issuing from the intrusive. They are, therefore, suitably termed *pyrometasomatic* deposits.

Under the general heading of form and texture of these deposits, the same author includes the following detail: "Fissures may guide the solutions, and transitions to veins may be formed by deposition along them." [4a] But it seems clear that Lindgren is here merely explaining how, within the limestone, there may arise vein-like deviations from the usual irregular replacements; in other words, that this is a structural detail and that no *genetic* distinctions are implied.

Other writers have intimated or assumed that the reactions between the hot intrusive body and the *immediately adjacent* limestone are necessary, or at least are highly favorable, for the formation of this pyrometasomatic type of deposit.

At Tepezala and other similar deposits [5] the various conditions and mineral associations of the pyrometasomatic group of ore deposits are present, but there is strong evidence that the ore solutions were distinctly later than the period of intrusion and rose from a deep-seated source along fissures formed after the intrusive had consolidated. At Tepezala, the fault zones along which the ores occur follow in part the intrusive contacts, but also cut the intrusive, and contain the same minerals regardless

[4] *Op. cit.*, p. 696.

[4a] *Op. cit.*, p. 700.

[5] J. E. Spurr, *Op. cit.*, pp. 719 and 725.

of the type of wall rock. It is apparent that the immediately adjacent portion of the intrusive rock was not the source of the ore solutions; they must have risen from depth, perhaps from the main, unexposed, deep-seated parent magma. Therefore, these deposits must necessarily be classified as *pyrometasomatic vein deposits,* and thus stand as a transition group between pyrometasomatic deposits as described by Lindgren and hydrothermal vein deposits in the usual sense.

Of interest in this connection is the proposal by Graton [6] that the pyrometasomatic deposits are not an independent type but merely a subdivision of the hypothermal group in which the special nature of the minerals as well as certain of the structural characteristics are a direct consequence of the character of the wall-rock, which is usually limestone. With further reference to that view, Professor Graton suggests that (1) where the (high-intensity hydrothermal) solutions do not come in contact with limestones, any deposits formed will be of the normal hypothermal type as defined by Lindgren; (2) where solutions of the same kind and physico-chemical intensity are liberated at, or ascend along, the intrusive-limestone contact, the conventional *contact-*metamorphic irregular replacement deposits are produced; (3) where the solutions in passing from their source permeate first through non-limestone rock and then reach limestone without having lost too much of their physico-chemical vigor, pyrometasomatic replacement deposits (of the conventional type except in respect of being distant from the intrusive contact) may be formed in the limestone; and (4) where solutions of the same kind and intensity as before are localized along fractures within the limestone away from the contact, they may readily yield what might properly be called pyrometasomatic *veins;* and where these same localizing fractures persist upward or outward from the limestone into other rocks, the solutions may nevertheless continue to deposit in these non-limestone rocks the characteristic lime-silicate mineralogy because of their having already passed through the limestone and acquired lime therefrom.[7]

[6] The Depth-zones in Ore Deposition, ECON. GEOL., vol. 28, p. 531, 1933.

[7] Personal communication.

Subdivision (4) of the foregoing explanation would seem to fit the facts at Tepezala, not only for those portions of the veins which have one or both walls of limestone but also for those portions which are included within the intrusive; in these latter instances it would be necessary to assume that the solutions acting there had earlier in their journey come sufficiently into contact with limestone to have acquired the requisite amount of lime for the skarn minerals.

This view that the ores are merely a special phase of hydrothermal deposits is likewise in accord with the local evidence that the solutions were evolved after the known portions of the intrusive had consolidated. In a recent paper, Harrison Schmitt [8] says:

> It seems likely that the primary factor in the localization and association of "stocks," contact metamorphism and ore is a deep-cutting break of one sort or another in the earth's crust, that the contact pyrometasomatic deposits are not derived from the "stocks" but that their association is the result of localization along mutual outlets to the earth's surface.

While this general idea seems to fit the case at Tepezala, it should be pointed out that the liquid magma, which now constitutes the intrusive stocks, and the solutions that formed the ores did not, in that district, ascend along exactly "mutual outlets"; instead, they probably arose along different fissures, of somewhat different age, which tapped different parts of the parent magma chamber.

Source of the Solutions.

From the surface extent of the intrusive rock and the position, dip and strike of the veins, inferences may be made as to their projection in depth and the probable source of the ore solutions. The highly generalized sketch (Fig. 2) shows the relations at Tepezala more clearly. It appears from this that the ore solutions were not derived from the uppermost central portion of the magma that forms the intrusive bodies; rather they emanated

[8] Structural Association of Certain Deposits in Southwestern United States and Northern Mexico, A. I. M. E., Contribution 38, 1933.

from lateral portions of the magma chamber, where for some reason the solutions gathered in preference to the central portion of the rising magma column.

Whether or not the assumption is correct that the ore solutions came from the marginal areas of the magma chamber of course cannot be proven. The marginal source of the ore solutions has been suggested by others who have studied different deposits, and at Tepezala a similar conclusion appears to be warranted. Why this should be the case is difficult to understand unless, as a post-consolidation effect, the marginal areas are most subject to fault strains and in this way the pathways are produced for the ore solutions which follow the act of intrusion.

SUMMARY.

The Tepezala occurrence presents a clear-cut case of ore deposits having pyrometasomatic mineralogy combined with the structure of distinct veins closely related to intrusive bodies, both stocks and dikes. The main veins cut both limestone and the rhyolite stock. The sulphide minerals are associated with abundant diopside, hedenbergite, epidote and quartz as vein gangue-minerals. The marginal alteration associated with the veins consists of an intergrowth of the same lime-silicate minerals, namely, fine-grained diopside, hedenbergite, epidote, together with quartz. This alteration affects both intruded and intrusive rock and is considered to be the first work of the solutions as they rose along the fractures. From the field relations it has been concluded that the solutions were not derived from the immediately adjacent intrusive, but from a much deeper-seated magma chmber. The deposits are considered to be of Tertiary age.

GUANAJUATO, GTO., MEXICO,
AND
MOROCOCHA, PERU,
May 17, 1935.

THE IRON ORE DEPOSITS OF THE ILIMPEIA RIVER, EASTERN SIBERIA.[1]

VLADIMIR SOBOLEV.

INTRODUCTION.

THE iron ore deposits of the Ilimpeia River[2] present a new instance of a special type of magnetite deposits within the Siberian platform. This type is so peculiar that it has no analogue among other well known types, and is not only of practical, but also of scientific interest.

As the structure of the Siberian platform and the petrology of its igneous rocks—the Siberian traps—is little known except for the work of the last fifteen years, as yet largely unpublished, and as the world literature up to the present time gives erroneous conceptions of these traps, the geology and petrology will first be briefly set forth, followed by the description of the deposits themselves.

GEOLOGY.[3]

The Siberian platform embraces the large area between the Yenisei and Lena rivers. On the south it approaches the foothill ridges of the Sayanskii Range (Saian Range); on the north it extends over the mostly unexplored region of the Khatanga and Anabara rivers. The sedimentary rocks of the platform are

[1] Published with the permission of the Director, Centr. Geol. and Pros. Inst., U. S. S. R.

[2] Discovered by the author in 1931, during a study of the Siberian traps, carried on under the direction of the Petrographical Section, Centr. Geol. and Pros. Inst.

[3] In addition to my own observations, the following literature was consulted on this subject:

Obruchev, S.: The Tungus Coal Basin (southern and western parts), Vol. 1. Trans. United Geol. and Pros. Survey, U. S. S. R., f. 161.

Rojkov, B.: Material on the Mineralization of Siberian Traps. Trans. Ea. Siber. Geol. and Pros. Trust, f. 3.

Some new data kindly furnished by V. P. Levsky have also been utilized.

almost horizontally bedded, being slightly folded only at the periphery. In general, it has a concentric structure. Along the edges is bedded Lower-Paleozoic. The central part is occupied by Upper-Paleozoic and Mesozoic (Carboniferous-Jurassic), the so-called Tungussian, which is divided into two sections: (*a*) Lower productive section (sandy deposits) and (*b*) upper tuff section. Over the tuffs extends a thick layer of trap, which, according to Obruchev, extended before erosion over the whole platform. These traps are now found in the center of the platform and on the most elevated portions of the plateau.[4]

Within the Lower-Paleozoic and the productive section of the Tungussian series, are numerous trap sills, and within the tuff section are dikes and intrusions of irregular form.

Volcanic activity began during the Upper Carboniferous, and reached its greatest intensity during the Mesozoic period. The upper boundaries of the traps are not established with certainty, but the evidence suggests that the extrusions ended before the Upper-Jurassic. The volcanism occurred in eruptions that emitted a great amount of tuff; these tuffs attain more than 500 meters in thickness and cover an area of some tens of thousands of square kilometers. Later, there occurred extrusions of thick flows; the intrusions are partly younger, partly synchronous with them. The hydrothermal activity of the trap magma caused the formation of the magnetite deposits.

PETROGRAPHY.[5]

As mentioned above, the only igneous rocks in the region of the Siberian platform are trap rocks of the gabbro-basaltic group. Effusive varieties are represented by fine-grained olivine diabases in the upper portions of the traps, passing into amygdaloids and glassy basalts, and spilites. The diabases of the flows, when examined microscopically, are almost indistinguishable from those of the minor intrusions, and it is still more difficult to determine the character of their occurrence in the field.

[4] On Rojkov's map their extent is exaggerated.

[5] Based chiefly on my own observations.

The most common type of intrusive traps (playing an important rôle in the platform structure) is a medium-grained poikilophitic olivine diabase. The principal minerals are plagioclase (An_{60}-An_{70}), monoclinic pyroxene (pigeonite with $2V = 46°$-$56°$), and olivine of two generations, (1) spherical grains, poor in iron (35 per cent Fe_2SiO_4), and (2) ophitic zonal grains of ferrous olivine (50 per cent Fe_2SiO_4). In many places there occur glomeroporphyritic accumulations of basic plagioclase (An_{90}) of the first generation. Closely associated with the olivine are micropegmatite and quartz, filling the interstices. There are also needles of apatite and the ore mineral magnetite, usually in skeleton forms.

Peculiar forms of the trap resulting from the accumulation of earlier-formed crystals (the " differentiation in the proto-enriched direction " of Vogt [6]) are represented by the anorthite diabases, consisting of more than 50 per cent of tabular basic plagioclase (An_{90}) within normal (labradoritic) ophitic diabase. Probably of the same origin are the diabases carrying hypersthene and generally rich in olivine. It is to be noted that the hypersthene in these rocks is crystallized around monoclinic pyroxene, and corroding the latter, contrary to Bowen's statements. Chemically, these diabases are characterized by a minor coefficient of FeO : MgO.

The trap intrusions commonly show schlieren and irregular veinings of coarse-grained varieties formed by the residual portions of the trap magma, rich in volatile components. Commonly they consist of more acid plagioclase, monoclinic pyroxene rich in iron, and micropegmatite. Fayalite has been observed,[7] and apatite is abundant. Chemically, these rocks are somewhat acidic, have a high content of alkalies and a marked predominance of iron over magnesium (FeO : MgO = 10 and more). The presence of fluorine is also notable.

These rocks are typical diabase-pegmatites. With them are connected veinlets of pink granophyre formed at the beginning

[6] Vogt, J. H. L.: The Physical Chemistry of the Magmatic Differentiation of Igneous Rocks. Videnskap. Skrifter, I Mat.-Natur. Klasse 1924, 15, p. 7 *et al.*

[7] Sobolev, Vladimir: Quartz-fayalite Diabase-pegmatite, Lower Tunguska. Mem. Soc. Russe de Mineralogie, Ser. II, vol. 62, l. 2, 1933.

of the hydrothermal stage, and, according to Lane, under aqueo-igneous conditions.[8] In exceptional cases the differentiation proceeded otherwise, and during the final stages there resulted teschenites and alkaline leucocratic veinlets.[9]

The contact metamorphism of the traps, especially of the sills, is as a rule extremely insignificant, and this suggested the conclusion that volatile components were generally scarce in the trap magma.[10] Such a conclusion, however, is absolutely wrong. On the contrary, these traps are a striking example of a basic magma containing a profusion of volatile components,—a view which is gaining numerous adherents and is vigorously defended by Fenner [11] and Lodochnikov.[12] Such a condition is readily seen in several vertical intrusions where the volatiles could not readily escape. Here, instead of tuffs and other rocks, are large zones of skarn-like garnet and pyroxene-garnet rocks, formed by additions of oxides of Ca, Mg, and Fe, and also some SiO_2. The concentration of the volatiles also caused the formation of the diabase-pegmatite and the leucocratic derivates within the trap intrusions themselves, and it accounts for the occurrence of a great variety of hydrothermal and in places pneumo-hydrothermal formations, of which the magnetite deposits are the most important.

IRON ORE DEPOSITS.

The Ilimpeia River basin in almost its entire extent is occupied by the tuff formation of the Tungussian series. The effusives are almost absent here. The intrusive traps are concentrated at two points; near the river mouth, and along the middle of its course, below its curve to the north. There is some basis for the

[8] Lane, A.: Segregation Granites. Jour. Geol., vol. 30, 1922.

[9] Sobolev, Vladimir: Alkaline Dike in the Traps of the Ilimpeia River. Mem. Soc. Russe de Mineralogie, Ser. II, vol. 62, l. 2, 1933.

[10] Loewinson-Lessing, F., Günsberg, A., and Dilaktorsky, L.: Die Trappe des Udinsk-Tuluner Rayons und Des Bratsker Rayons in Ost-Sibirien. Leningrad, 1932. S. 10.

[11] Fenner, C. N.: Crystallization of Basalts. Amer. Jour. Sci., vol. 18, no. 105, 1929.

[12] Lodochnikov, Wartan: Serpentines and Serpentinites and the Petrological Problems Connnected with Them. Problems of Soviet Geology, 1933, no. 5.

supposition that only the upper portions of the intrusions outcrop at the surface.

Along the Ilimpeia River only three deposits worthy of examination, all of similar character, were noted. Everywhere are found groups of irregular branching veins, 1 to 2 meters wide, of almost pure magnetite, enlarged in places to greater widths.

Along the walls there is much calcite; in the veins are bunches of calcite, geodes of quartz and chalcedony, and rarely of pyrite. The tuffs along the vein-contact are strongly altered to a fine-grained garnet rock (belonging to the grossular-andradite range, nearer to the former), which is quite analogous to the contact rocks of some of the trap intrusions. The ore mineral itself is of special interest; in some places it has a fine-grained to compact structure; in others it is crystalline, with irregular oblong crystals terminated by octahedral faces. The mineral is strongly magnetic, and during field work it was determined as magnetite.

An analysis made by Nikolaev, in the Geochemical Section of the Geological Institute, U. S. S. R. (I), and an analysis of the magnetite from an analogous deposit on the Chunia River, by J. N. Knipovich, in the same laboratory (II), gave the following results:

	I	II
Fe_2O_3	72.73	66.95
FeO	9.66	15.87
MgO	12.61	8.81
TiO_2	0.46	0.89
MnO	0.12	...
V_2O_5	trace	0.02

	I	II
$MgO.Fe_2O_3$	68.0	50.4
$FeO.Fe_2O_3$	28.0	47.0
$FeO.TiO_2$	1.3	2.6
Fe_2O_3	2.7	...

Allow for insoluble residue (quartz) and ignition loss.

As these analyses show, the composition of the mineral is quite uncommon. Instead of the expected magnetite, this is a magnesioferrite or, more precisely, an intermediate member of the

magnetite-magnesioferrite group.[13] This mineral has been known previously in the form of separate crystals (and never quite pure) in the explosion products of Vesuvius, Etna, Stromboli, Ascension Island, and in somewhat larger quantity in the metasomatic marbles of Kaiserstuhl.[14] It is everywhere associated with basic and alkaline (also basic) magmas. In the deposits here described it is found for the first time in great amounts.

ANALOGOUS DEPOSITS OF OTHER REGIONS.[15]

The other iron ore deposits of the Siberian platform are somewhat similar to the Ilimpeian deposits. They are all distributed along a large, almost meridional band extending from the Angara-Ilim ferriferous region to the Lower Tunguska River. The largest are situated in the Angara-Ilim region, where the veins attain a width of tens of meters, and may be followed along the strike for many kilometers. These are undoubtedly of great economic importance and value. The ore mineral here is closer to magnetite, although it is commonly characterized by an abnormally high MgO content.[16] The contact areas of pyroxene-garnet rocks here attain enormous size.

Deposits approaching the Ilimpeian in size are also found along the Chunia (Analysis No. II) and Stony Tunguska Rivers. These are similar in form and contact features, as well as in ore-mineral composition.

[13] The first one to discover MgO in these minerals was V. S. Popov, Tomsk, 1932.

[14] Hintze, C.: Handbuch der Mineralogie, Bd. I, l. 119, S. 33–34.

[15] Doktorovich-Grebnitski, S.: Description of the Iron Deposits of Nikolaevski Works, Government of Irkutsk. Trans. Geol. and Pros. Serv., U. S. S. R., F. 33, 1931, p. 3.

Obruchev, S.: *Op. cit.*

Smirnoff, S. S.: On the Mineralogy of the Mid-Siberian Platform. Problems of Soviet Geology, vol. LV, no. 10, 1933.

Anikeev, N., and Zorin, V.: Angara-Ilim Iron Ore Deposits of Eastern Siberia. Trans. East. Siber. Geol. Trust. T. 5, 1934.

[16] According to recent analyses, not yet published, kindly communicated to me by N. Anikeev, the ore mineral of the Angara-Ilim deposits contains 45 to 55 molecular per cent of $MgO.Fe_2O_3$.

ORIGIN OF THE IRON ORES OF THE SIBERIAN PLATFORM.

It is at present definitely acknowledged that these iron ore deposits are connected with the trap magma. Doubts regarding this connection are based (1) on the rarity of such a type of occurrence, and (2) on prejudice regarding the poverty of the basic magma in volatiles. It is true that iron-ore deposits of the size and character of those connected with the trap plateau are not known elsewhere, but minor iron-ore deposits originating from diabases are not at all rare.[17] Nevertheless, it must be noted that these are only small contact-deposits approaching in type the common deposits connected with acid and neutral magmas. In morphology the Siberian platform deposits have no analogues.[18] The whole character of the deposits here is so unusual that it is logical to consider them the result of a unique original process.

As to the second objection, concerning the relative poverty of basic magmas in volatiles, this view must now be considered out of date.

What essential evidence and argument can really support the connection of these deposits with the traps?

1. It is a fact that all these peculiar deposits are situated within the limits of the Siberian platform and that the only igneous rocks composing this platform are the traps. The nearest outcrops of acid rocks are separated from the Ilimpeian deposits by more than 1000 kilometers. Thus, if one supposes that these deposits are not connected with the trap magma, one is obliged to infer the existence at depth of some other rocks which not only do not outcrop on the surface but do not even betray themselves by a dike series.

2. Other evidence is shown in the peculiarity of the mineralogy and geochemistry of the deposits.[18] In ore deposits allied to acid rocks the chief added products are SiO_2 and Al_2O_3, but here they are mainly the oxides of bivalent metals. The addition of SiO_2 is extremely insignificant. Quartz and silica make their appear-

[17] Hickok, W. O.: The Iron-Ore Deposits at Cornwall, Pennsylvania. ECON. GEOL., vol. 28, no. 3, 1933.

[18] Smirnoff, S. S.: *Op. cit.*

ance only during the later stage of the process, and in relatively negligible amounts. The composition of the ore mineral itself shows that it is a peculiar type, connected with a basic magma.

3. As a third proof may be noted the absolute analogy of the skarn-like rocks along the contact zones of the deposits with those of certain trap intrusions. In the Ilimpeia River region, where these zones around the ore-bearing veins are insignificant in comparison with those in the Angara-Ilim region, are large outcrops of garnet rock with sulphide veins of a similar origin.

4. Finally, there may be considered the occurrence of analogous magnetite veins (of minor dimensions) in direct contact with trap intrusions, and the transitions from magnetite to pure calcite veins. These are commonly developed within the platform, and are undoubtedly connected with the traps.

As in most cases no direct connection is observed between the trap intrusions and the deposits, and as they are insufficiently investigated, the scheme of their origin can be traced only in a general way. The fluid solutions freed from the trap magma during its transition into zones of lowered pressure probably ascended along open fissures. During the first, or pneumatolitic phase, they replaced the wall rocks metasomatically, changing them to skarns. The process must have been of extreme intensity, since the final product is almost independent of the original composition of the rock. During the next stage,—probably hydrothermal, as is suggested by the presence of crustification and other uncommon structures in some of the veins,—there occurred the calcitization of the skarns and the formation of the magnetite veins. Finally, during the third, or low-temperature stage, the deposition of later calcite, quartz, and chalcedony took place.[19]

Once more it should be emphasized that this is only a general sketch of the processes; the working out of details is yet to be performed by future investigations. As one of the most interesting questions awaiting solution may be mentioned the absence of such deposits in other platforms built up by analogous traps, e.g. the Karroo, Brazil, and others. The cause must be sought in the

[19] For the Angara-Ilim deposits, Doktorovich-Grebnitski presents a more complex origin, including four stages.

peculiar development of the volcanic cycle of the Siberian platform. This question and many others must be solved by further petrological and geological research on the traps, which until recently were almost unknown. The geologic province in which they occur also presented a *terra incognita.* Now, numerous expeditions to the farthest boundaries of the country, on the one hand, and detailed exploration of the ferriferous regions, on the other, will no doubt throw much light on this most interesting scientific problem.

CENTRAL GEOLOGICAL AND PROSPECTING INSTITUTE,
LENINGRAD, U. S. S. R.,
Jan. 16, 1935.

LEAD–BISMUTH ORES IN BLEKA, SVARTDAL, NORWAY.

CARL BUGGE.

INTRODUCTION.

SOME years ago I received for examination a sample of ore from the old Bleka mine at Svartdal, in southern Norway. The sample, which was sent me by Mr. Werner, the owner, weighed about 12 kilograms, and consisted of quartz with needles and aggregates of an ore mineral which, during its earlier exploitation, had been considered to be a bismutite. Some specks of gold and a few of chalcopyrite were visible. The intention was to find someone who would take an economic interest in the mine and reopen it. I showed the ore to several persons, but at that time there was not much interest in gold and no mining was started.

In 1932 the interest in gold was so great that I thought the Geological Survey ought to spend some money in order to examine the occurrence. At first I had the samples crushed at the Oslo Laboratory for Testing Materials, whereupon Mr. F. Egeberg treated the material by flotation in his laboratory in Oslo. The sample was ground in a ball mill until all the material passed a 48-mesh screen, and 45 per cent passed a 200-mesh screen. My intention was first to make a concentrate for analysis.

The flotation concentrate was 1.15 per cent by weight, and 98.85 per cent waste, indicating a high ratio of concentration. Assays by Mr. Stören of Kongsberg gave 1260 grams gold and 2600 grams silver, per ton of concentrate.

Such high assays of gold and silver prompted me to go to Bleka, where the foreman, Halvor Johnsen Svartdal, assisted me in examining the veins. At the same time new samples were taken, among others of chalcopyrite, which mostly occurs in the wall-rock of the main vein.

Composition of Concentrate.

The analysis[1] of the concentrate showed:

	%
Insoluble	12.12
Bi	36.44
Pb	19.91
Cu	2.38
Zn	0.39
Fe	14.75
S	13.63
Te	0.06
Se	not present in detectable amounts
Au	0.126
Ag	0.260
	100.066

The high iron content evidently came mostly from the steel balls of the mill, and in the calculation of the mineral composition, the excess of iron above that needed for chalcopyrite is disregarded. The insoluble matter is also disregarded and a recalculation to 100 per cent is made. Lead is figured as PbS, bismuth as Bi_2S_3, zinc as ZnS, and silver as Ag_2S. The remainder of the sulphur is placed in chalcopyrite, $CuFeS_2$; remainder of the copper is calculated as Cu_2S. Tellurium is figured as Bi_2Te_3 and the gold as native.

This gives the following result:

	Sum	Bi	Pb	Zn	Cu	Ag	Fe	Te	S	Au
Bi_2S_3	59.88	48.62							11.26	
Bi_2Te_3	0.16	0.08						0.08		
PbS	30.76		26.64						4.12	
ZnS	0.77			0.48					0.29	
Cu_2S	1.05				0.84				0.21	
Ag_2S	0.39					0.30			0.09	
$CuFeS_2$	6.80				2.38		2.04		2.38	
Au	0.144									0.144
	99.95	48.70	26.64	0.48	3.22	0.30	2.04	0.08	18.35	0.144

[1] Silver and gold analyses by Mr. Stören; the others, by Mrs. M. Klüver.

Practically no galena was seen in the ore, and the lead, therefore, must be combined with bismuth, as one or more lead-bismuth minerals. It is probable that ZnS, Cu_2S and Ag_2S are also combined along with the PbS, whereas Bi_2Te_3 is supposed to combine with Bi_2S_3. As far as copper is concerned, Ramdohr states[2] with respect to bismuth ore from Bleka, that the ore contains copper and probably is "emplectite" with a composition of Bi 77.61, Cu 3.06 and S 18.17 per cent.[3]

If bismuth, lead and corresponding sulphur are recalculated to 100 per cent, the average analysis shown in Table I, No. 1, is obtained. In Nos. II and III are shown Sjögren's analysis of galenobismutite from the "Kogruben" in Nordmarken.[4] In No. IV is shown the theoretically calculated composition of galenobismutite according to the formula $PbS.Bi_2S_3$.

TABLE I.

	I.	II.	III.	IV.
Bi.....	53.68	54.69	54.13	55.62
Pb.....	29.36	27.65	27.18	27.43
S.....	16.96	17.35	16.78	16.95
	100.00	99.69	98.69	100.00

It is evident that there is agreement between analysis I, of the ore from Bleka, the ore from "Kogruben," and the one theoretically calculated. It is, therefore, probable that the Bleka ore contains a relatively large amount of galenobismutite. As the analysis is made on a flotation concentrate and not on a picked sample, it cannot be stated just how definite the relations are. For comparison, I refer to a description of the Swedish occurrences of lead-bismuth minerals.[5]

Bleka Bismutite.—I have also analyzed a sample of plumbifer-

[2] Ramdohr, P.: Arkiv. für Lagerstättenkunde, 1924.

[3] See also: Schneiderhöhn-Ramdohr: Lehrbuch der Erzmikroskopie Bd. II, p. 87.

[4] Geol. fören. Förh. Bd. IV, 1878.

[5] *Idem.* See also Flink's description of galenobismutite, weibullite, platynite and cosalite (Arkiv. för Kemi, Min. & Geol., Bd. 3, 1910); and Weibull's description of seleniferous galenobismutite from Falun (Geol. Fören. Förh., B. VII, 1885).

ous bismutite from Bleka, showing undulating cleavage, as follows:

	%
Insoluble	35.82
Bi	47.20
Pb	2.35
Cu	0.63
Zn	trace
Fe	0.60
S	11.58
Se	0.07
Te	0.15
	98.40

The insoluble is disregarded and the result is recalculated to 100 per cent. Bi is figured as Bi_2S_3, Se as Bi_2Se_3, Te as Bi_2Te_3, Pb as PbS, Cu as $CuFeS_2$. Gold and silver are not determined. The following mineral contents are obtained:

		Bi	Pb	Cu	Fe	S	Se	Te
Bi_2S_3	92.28	75.03				17.25		
Bi_2Se_3	0.24	0.13					0.11	
Bi_2Te_3	0.50	0.26						0.24
PbS	4.33		3.75			0.58		
$CuFeS_2$	2.91			1.01	0.89	1.01		
	100.26	75.42	3.75	1.01	0.89	18.51		

If chalcopyrite is disregarded, and if Bi_2S_3, Bi_2Se_3 and Bi_2Te_3 are figured together, the result is:

	%
Bi_2 (S, Se, Te)$_3$	95.56
PbS	4.44
	100.00

When the molecular proportions are calculated, the result corresponds approximately to 10 Bi_2 (S, Se, Te)$_3$. PbS.

GJUV, HJARTDAL, BISMUTITE.

Also, I have the following analysis of a bismuth concentrate from a quartz vein in Gjuv, Hjartdal, located about 10 kilometers east of Bleka.

	%
Insoluble	9.60
Bi	47.25
Pb	5.25
Cu	1.82
Zn	0.14
Fe	10.76
S	23.90
Te	0.14
Se	0.008
	98.878

Analysis made by Mrs. M. Klüver.

The quartz vein occurs at the border of the same gabbro as at Bleka. Mr. Stören found 175 grams gold per ton. The mineral contents have been calculated as with the Bleka concentrate. Bismutite, chalcopyrite and pyrite were seen in the ore; galena is present, but in this sample none was found. The results are as follows:

		Bi	Pb	Zn	Cu	Fe	Te	Se	S
Bi_2S_3	65.09	52.72							12.37
Bi_2Se_3	0.03	0.02						0.01	
Bi_2Te_3	0.32	0.16					0.16		
PbS	6.80		5.83						0.97
ZnS	0.23			0.15					0.08
$CuFeS_2$	5.90				2.04	1.79			2.07
FeS_2	21.63					10.05			11.58
	100.00	52.90	5.83	0.15	2.04	11.84	0.16	0.01	27.07

Disregarding ZnS, $CuFeS_2$, FeS_2 and undissolved, the result is:

Bi_2 (S, Se, Te)$_3$	90.55%
PbS	9.45%
	100.00%

Calculating the molecular proportion, I find that the formula $n\ Bi_2(S, Se, Te)_3.PbS$, gives as a value of n, a little above 4.

RESUMÉ OF RESULTS.

The investigation shows that the ore occurring in Bleka is mainly galenobismutite. Small amounts of bismutite were also found and traces of galena were observed. Furthermore, Ramdohr has, as mentioned, found emplectite.

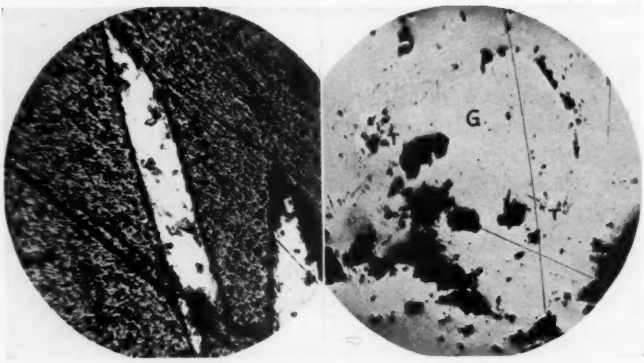


FIG. 1. Needles of galenobismutite in quartz.

FIG. 2. *G*, galenobismutite. *T*, small grains of the white ore mentioned.

According to Mr. Lewin, there is possibly about one per cent of galena in the ore. That it is mostly *galenobismutite* is shown by the analysis of the average sample of the flotation concentrate. Furthermore, a visual examination of the ore reveals that the bulk of it is a grayish-white crystalline mass, and analyses of selected pieces show a lead content that corresponds to galenobismutite, namely, 30.38 per cent lead and 1.95 per cent insoluble. This mass occurs along the walls of the veins and along fissures in the quartz veins. Its structure is in part radiating, and some needles extend toward the middle of the quartz vein. In the coarser crystalline types, cleavage is observed. Polished sections reveal a white to grayish-white color and a few cleavage cracks.

The *bismutite* is established by analysis of picked samples. To check the results, an analysis of a sample from Bleka was made. This gave 3.56 per cent lead and 0.17 per cent undissolved. It resembles the galenobismutite, but has a more pronounced cleavage. Under the microscope it shows about the same color and cleavage cracks as galenobismutite. Macroscopically, there is possibly a little tinge of red in the otherwise

white ore. Wide, bent lamellae with distinct cleavage are common, and cleavage cracks perpendicular to the general cleavage were observed.

In the galenobismutite as well as in the bismutite, the microscope reveals small grains or lenses of a mineral with a white to yellowish-white tint. Some of the cleavage cracks pass through these grains and into surrounding bismuth ore. A few independent cleavage cracks also occur. The grains are so small that it was impossible to pick out the necessary material for analyzing. They might be native bismuth, tellurium bismuth, or a silver or gold telluride. They do not, however, resemble argentite. In the mineral calculation I have assumed that the total amount of gold is native gold but this is only an unproved assumption. The specks of gold observed generally occur near the bismuth ore, but mostly in the quartz. It is my intention to continue this work in order to determine the nature of these small specks.

GEOLOGICAL RELATIONS.

The object of this communication is to supply information regarding galenobismutite at Bleka. Geologically, the ore occurs in quartz veins in a gabbro dike that cuts quartzite. A few veins also occur in the quartzite. The gabbro dike is known to be more than 20 km. long and up to 2.5 km. wide; it is probably larger. The unaltered rock shows a hyperitic texture. The border of the dike adjacent to the quartzite is quartz diorite, which I presume has been formed by assimilation of quartzite. The quartz diorite displays spheroidal structure.[6]

At Bleka there are 13 to 15 gold-bearing veins. The main vein, which penetrates the gabbro, is about 900 meters long and averages from 0.3 to 0.5 meters wide; in one place a width of 2.2 meters has been recorded. The gangue consists of dominant quartz, with calcite, barite, brown spar, tourmaline, and traces of fluorspar. The tourmaline occurs as brown and black needles, and in places is abundant. In places, albite has been noted.

In addition to the lead-bismuth minerals, chalcopyrite is im-

[6] Bugge, C.: Norsk geol. Tidsskr., B. XII, p. 166.

portant at Bleka. It occurs mostly in the altered wall-rock, which consists of quartz, muscovite, chalcopyrite, also considerable quantities of pyrite and some sphalerite. Galena is uncommon but occurs in some of the veins, as for example, at Svervelien.

As to other Norwegian occurrences of these ores, Professor J. H. L. Vogt [7] states that in Klovereidnuten, at Bandaksli, native bismuth, bismutite, and probably a lead-bismuth mineral have been found, and that a qualitative examination shows lead, a little copper and silver, much bismuth and sulphur. Vogt suggests that the mineral may perhaps be cosalite.

In the Mosnap mine and possibly also in the Moberg mines at Skafse, a little bismuth telluride (Bi_2Te_3) has been found. The same mineral has also been observed by Helland in the veins of Bömmelöen.

The prospecting which is now going on at Bleka will, I hope, throw more light on this interesting occurrence.

NORWEGIAN GEOLOGICAL SURVEY,
OSLO, NORWAY,
May 19, 1935.

[7] Norske Ertsforekomster, Arch. f. Math. eg Nat. Bd. 10, 1886.

SPECTROGRAPHIC EVIDENCE ON ORIGIN OF ORES OF MISSISSIPPI VALLEY TYPE.

L. C. GRATON AND G. A. HARCOURT.

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INTRODUCTION.

WITH the increasingly wide acceptance of magmatic influences as responsible for the origin of sulphide ores, interest focuses more and more on examples regarded as exceptions. Among these, the plainly supergene and local rearrangements (whether or not involving enrichment) of previously-formed sulphide concentrations offer no problem in this connection. But another great group of sulphide ores, typified by the lead-zinc deposits of the Mississippi Valley, has not as yet been accorded a secure place in the grand family of magmatic affiliation. The ores belonging to this type, because relatively simple and monotonous in charac-

ter and environment, present little that is inherently and obviously diagnostic of their origin. Perhaps it is largely on this account that disagreement persists regarding them. In any event, detection in these ores of specific features possessing genetic significance is plainly to be desired.

This paper relates particularly to the presence of comparable quantities of the same relatively rare elements in the sphalerite of these ores as occur in the sphalerite of deposits now generally accepted as of magmatic lineage. We submit that this parallelism is to be interpreted as presumptive evidence of substantial similarity as to source and as to processes of accumulation and precipitation for both sets of deposits. And if choice must be made between the "meteoric" and the magmatic as the single origin *for the lot as a whole,* few could now deny that the evidences in support of the fundamental validity of the magmatic origin are by far more direct and inescapable than are the evidences for a "meteoric" origin for all these ores or for any subdivision of them. Moreover, the relative quantities of these rare elements in sphalerite are found to vary serially in such manner as to be rationally explained if the Mississippi Valley type of ores constitute the low-intensity end-member of the hydrothermal group, all other subdivisions of which are now firmly established as magma-derived. There is appended a brief discussion of other minero-chemical considerations which point to the same conclusion.

It has long been known that sphalerite from numerous localities, when examined spectroscopically, discloses the presence of various elements in quantities that would be missed by the more customary analytical methods.[1] Among the less common of these elements,

[1] De Gramont, A.: Bull. Soc. Min., France, vol. 18, pp. 171–173, 1895; Hartley W., and Ramage, H.: Trans. Jour. Chem. Soc. Lond., vol 71, p 547, 1897; Urbain, G.: Comptes Rendus, vol. 149, p. 602, 1909; del Campo y Cerdan, A.: Anal. Fis. Quim., vol. 12, 1914, p. 80 et. seq; Scutt, W.: Phil. Mag., ser. 7, vol. 1, p. 1007, 1926. For recent details on Ga and Ge, see various papers by J. Papish and collaborators and by V. M. Goldschmidt and collaborators; and for additional older references, consult Doelter. See also Claussen, G. E., Amer. Miner., vol. 19, p. 221, 1934, and Hassler, E. L., Ann. Rept., U. S. Nat'l Research Council, Div. Geol. and Geog., for 1934, Appendix J; both of these appeared when we were checking our determinations quantitatively.

Cd, Ga, Ge and In appear frequently, and Th has been reported from several British sphalerites. Since most of the sphalerites so studied have come from deposits admittedly or presumptively of either hydrothermal or some other magma-related origin, we decided to investigate by means of the spectrograph sphalerites from a number of deposits which many geologists still ascribe to "circulating meteoric waters." In order to check prior results and to calibrate the sensitivity of our own procedure, we also included sphalerites from other types of deposits, including occurrences for which a magmatic source is now generally accepted.

For helpful suggestions, the writers are under grateful obligation to their associates, Mr. Harry Berman and Mr. R. S. Moehlman.

PROCEDURE.

The determinations (made by the junior author) were recorded on 4″ × 10″ Eastman "33" plates (which have a useful range between 2400 and 5000 Å) from arc excitation through a medium Hilger quartz spectrograph. The material for analysis was carefully selected under the microscope to insure the absence of other minerals than sphalerite. The usual precautions against electrode contamination were observed. Each "determination" included impressing on the negative (without moving the latter), by means of a Hartmann diaphragm, a series of exactly tangent narrow strips comprising the successive spectra of (1) the empty electrodes, (2) a "standard" containing balanced proportions of 50 elements—Hilger's "R. U. Powder," (3) the sphalerite sample, (4) the iron arc or the copper arc, and (5) (when needed) thorium nitrate—since the R. U. powder does not include thorium. It was thus possible to identify the elements present in the sphalerite specimen by direct registry with known persistent lines in the adjacent standards, thus eliminating all uncertainties of comparative measurements.

For each of the elements found, except for the dominant Zn, a persistent line was chosen and its intensity determined, by comparison with a standard negative according to an arbitrary scale ranging from 0 to 10 (with unmistakable "traces" rated as 0.1).

In this way, relative quantitative values could be assigned to each element in each sample. A considerable number of these values have been checked against more precise quantitative determinations (down to the fourth decimal place of percentages) by means of the logarithmic step sector and photometric density determinations standardized against a series of synthetic powders of ZnS containing known proportions of the elements to be determined. In all these instances the general order of magnitudes represented by the arbitrary 0–10 scale has been confirmed.

RESULTS.

Table I gives the results secured on eighteen specimens from eleven widely-scattered metallogenetic regions. Six specimens from five regions, comprising group *A*, would probably be generally accepted as of magmatic affiliation. Ten specimens in group *B* represent ores from the Mississippi Valley proper, the

TABLE I

	Mn	Fe	Cu	Pb	Ag	Sn	Bi	Sb	Cd	Ga	Ge	In
A												
Magmatic Group												
Butte, Montana	4	4	7	4	5		1		2	2	3	0.1
" "		1	3	2	2	0.1			4	0.1	1	1
Mammoth, Calif		5	5	8	4				4	1		0.1
Ouray, Colorado		0.1	0.1	3	3				4			
Clausthal, Germany	0.1	6	4	1	1			0.5	2	2	1	
Cerro de Pasco, Peru	0.1	6	2	2	1	1			2			
B												
Mississippi Valley Type												
Joplin, Missouri		3	4	8	2		1		4	1	5	0.1
" "		3	2	2			0.1		2	0.1	2	1
" "		2	4	0.5					4	0.1	2	0.5
Carterville, Missouri		2	4	0.5			0.1		4	3	1	1
Miami, Oklahoma		2	5	1					4	5	4	0.5
" "	3	6	6	3			2		4	5	1	0.1
Mascot, Tenn		2	5	1	2				4	1		1
Moresnet, Belgium		3	3	7	1				3		3	
Scharley, Silesia	2	3	4	3	0.1		0.1		4		0.5	0.1
" "		2	2	2	2		0.1		4		1	0.1
C												
Miscellaneous												
Franklin Furnace, N. J.	2	1	1						3			1
Edwards, N. Y.	1	6	4	1	1				2	0.1		

Mascot deposit in Tennessee, and the famous European ores of Moresnet and Upper Silesia. In group *C* are placed sphalerites from two deposits which may perhaps most conservatively be listed as of origin not yet universally agreed upon.

All of the eighteen sphalerites contain Fe, Cu and Cd, and all but one contain Pb. Ag, Ga and Ge are present in twelve specimens, and In is present in thirteen.

In the sphalerites of group *B* we found no Sn, as reported by Claussen and by Hassler, and no As, Co or Pd as found by Claussen. On the other hand, in this group we found Bi, In and Mn, not reported by Hassler or Claussen, Ag not found by Hassler, and Cd, Ga and Ge not detected by Claussen. These disparities of result are probably to be ascribed in part to differences in technique and in instrumental sensitivity among the various workers; but in larger measure, they are probably accounted for by actual compositional differences of different specimens. For example, we find Mn in one of our two sphalerites from the Miami district, but we check with Hassler in not finding it in the other, nor do we find it in the remaining specimens from the Tri-State region; like Claussen, we find Ag in a sphalerite from Joplin, but in only one of our three Joplin specimens. On the whole, the agreements between the three sets of results are much more striking than the disagreements. Since error is far more likely to consist in missing an element actually present than in reporting one that is really absent, it follows that *all* the elements reported for the sphalerites of group *B*, whether or not detected by all the workers, are probably actually present in sphalerites from these deposits, even if not present in every grain or tiny sample of those sphalerites.

In view of the indicated improbability that any single tiny sample, such as those tested, affords a complete representation of the contents of the sphalerite for that entire ore occurrence, we have made, from the data in the preceding table, simple arithmetical averages of the relative abundances of the several elements in each of the three types of occurrence, *A*, *B* and *C*. A glance at the table will show that such averaging is justified, since,

especially in groups *A* and *B*, what is true for any one specimen of that group is likely to be reasonably true for the majority of specimens in that group.

Fig. 1 is a graph of the averages thus attained; the several characters of line, continuous, dash or dotted, relate respectively to the

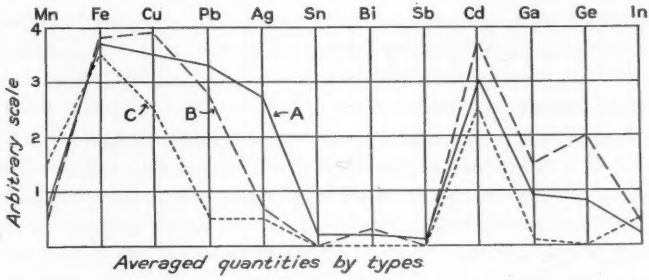

FIG. 1.

averages for types *A*, *B* and *C*. The graph makes it evident that the three types of occurrences show much more striking tendency toward parallelism than toward diversity.

ARGUMENT.

Significance of the Similarities.

It is thus seen that sphalerites from a number of deposits of the so-called Mississippi Valley type appear to contain quantities of the common elements, such as Fe, Cu and Pb, and of the rarer elements, especially Cd, Ga, Ge and In, which are approximately commensurate with those found in deposits admittedly formed by solutions of magmatic derivation.

In the complete absence of evidence to the contrary, it is to be assumed that these minor components were deposited at the same time that the enclosing sphalerite was formed. Stated otherwise, it seems altogether probable that these various sphalerites were deposited from solutions of just the right composition and under the proper physico-chemical environment to cause these other ele-

ments to attain saturation at the same time and be accommodated within the growing sphalerite individuals presumably in the same special manner in all cases.

Unfortunately experimental data apparently do not exist as to the range of limiting compositions and environments to which this particular kind and proportion of deposition is confined. But from the general knowledge on such matters, it would seem admissible to expect that such a special result as that in question implies its accomplishment under narrow and exacting limits; anywhere outside these narrow limits a different kind of result would be expected. The same idea may be put thus: it seems improbable that solutions of wholly different manners of derivation would, in the first place, possess all these elements in adequate quantities, and then that the relative solubilities of these elements with respect to one another would hold substantially constant despite great differences in the conditions causing and attending deposition. At least, it seems reasonable to hold that the burden of proof should rest on the contrary assumption that this same special result could be secured from solutions of widely divergent source and character operating under very unlike conditions of temperature, pressure and nature of precipitant.

Now it must be admitted that there is not universal agreement as to the composition and general character of the solutions from which were deposited the ores of Butte, Shasta County, or Cerro de Pasco. But there is now well-nigh universal agreement that these solutions were hot, that they operated under pressures quite different from the usual effective hydrostatic head of ground waters, and that their characteristics of composition were determined chiefly by their derivation as extracts from igneous magmas.

Likewise, there is no universal agreement as to details among those who adhere to the view that the deposits of the Mississippi Valley, Belgium and Silesia were formed from circulating groundwaters independent of igneous activity. But it is evident that any and all versions of that general non-magmatic conception of origin must involve profound differences as to composition of

solution, means and opportunities of acquiring solutes, and conditions and causes of solute deposition, as contrasted with the factors operative in the formation of hydrothermal deposits of magmatic ancestry. Indeed, except for common assumption of a water-rich solvent and common dependence on solubility and saturation, the two contrasting concepts of origin, the magmatic and the " meteoric," are almost as wide apart in their geologic and physico-chemical significance as are the methods of rock formation by magma crystallization and by detrital sedimentation.

As more or less direct representative of the mother-liquor of the magma, the hydrothermal solution did not deliberately choose its solutes but had these forced upon it, as it were, in whatever proportions the preceding crystal phases had failed to incorporate into themselves. On the other hand, according to the " meteoric " hypothesis, the ore-forming solution had deliberately selected and acquired its solutes by dissolution from the rocks through which it moved. By conventional chemical experience, such sequence of dissolution and precipitation should be a " purifying " action; the major component would be " purer " as precipitated than it had been before being taken into solution. Since, at the moderate temperatures and pressures assumed by the meteorists, there is no such difference in solubility between, say, ZnS and CdS as would correspond to their great difference in respective proportions in the sphalerites of the Mississippi Valley type, it would apparently have to follow that, if these two metals had been derived through leaching of source-rocks by the ordinary ground water, such source must have been relatively much richer in Cd with respect to Zn than are these known sphalerites. No facts of occurrence have been brought to light that support such kind of source.

If the sphalerites contained only one or two subordinate elements in common, and if the respective quantities of these elements happened to be of the same general order from sample to sample, such similarity might perhaps be regarded as a chance coincidence that happened despite widely different origins for different sphalerites. But as the number of such contained ele-

ments increases and the respective quantities thereof continue to hold to corresponding values, the possibility of explaining it all as coincidence becomes less and less tenable. Again it seems that the burden of proof should be on him who assumes a fortunate aggregation of chances rather than a common method of origin to explain the substantial number and degree of similarities which the spectragraphic data present.

It is obviously impossible to maintain that the facts here dealt with constitute positive and inescapable proof of a common origin for the sphalerites of group *A* and group *B*. Even if there were no other difficulty, our knowledge of the chemistry of this particular problem is too imperfect and the available spectrographic data are not sufficiently precise quantitatively. But it does seem justifiable to hold that the present facts afford strong presumptive evidence of such common origin.

We shall not here attempt seriously to labor the further point that *if* a common origin for all these sphalerites is to be accepted, the verdict must certainly be in favor of magmatic affiliation rather than the opposite. As against the vast array of accumulated evidence in support of magma-derived origin for many ores, the great underlying reason for assuming a non-magmatic origin for ores of the Mississippi Valley type appears to be the absence or scantiness of intrusive rocks of appropriate age known at or close to the surface in the regions where those deposits occur. But in the light of increasing disclosures of the great vertical distance [2] through which ore-carrying solutions may move and deposit away from the parent magma-source, this argument of absence or scarcity of igneous rocks at the level of the ore deposits is rapidly losing force. Genetic connection with unrevealed igneous bodies has had to be accepted [3] for certain deep-seated high-intensity deposits. It is surely no more difficult or illogical to make a corresponding assumption for these low-intensity ores of shallow-seated situs. Their points of striking analogy with the

[2] As, for example, at Morro Velho, Brazil. Cf. ECON. GEOL., vol. 28, pp. 533–534, 1933; see also pp. 535, 538 and 553.

[3] Lindgren, W.: Mineral Deposits, 4th ed., pp. 735–739, 1933.

outermost, feeblest-intensity phases in regions of pronounced hydrothermal zoning help to support such assumption.

Significance of the Differences.

Thus far, emphasis has been placed on the fundamental *similarities* of minor-component composition of the sphalerites. But no one would attempt to hold that all the sphalerites have been formed from exactly identical solutions under precisely equivalent conditions. If not, then—provided the preceding basic argument of compositional control by conditions is sound—one might expect to find some dissimilarities in sphalerite composition that would reflect the departures from exact identity of origin for the several groups of samples. As a matter of fact, the dissimilarities shown by the table of data appear to have significance in this respect, and deserve comment.

The deposits of group *A* all belong toward the more moderate [4] end of the hydrothermal depth-intensity range; that is to say, they come from either the upper mesothermal or from the leptothermal zone. The deposits of group *B*, by contrast, are universally accepted as having formed under less intense physico-chemical conditions; by those who ascribe these deposits to magmatic ancestry they are classified as telemagmatic or telethermal. On the other hand, the deposits near Franklin Furnace, put in group *C* [5] are regarded by Lindgren [6] and many others as belonging well toward the deepest and most intense known limit of the epigenetic range.

Given this classification as to position on the depth-intensity scale, the geologist could predict for each group the general type of minerals likely to be present, and thus the general association

[4] It seemed that deposits of such restrained physico-chemical intensity would show closer analogies to the still lower-intensity deposits of the Mississippi Valley type than would deposits lying nearer the high-intensity extreme of the scale. Epithermal sphalerites might have been better still; but in such ores, the extreme fineness of grain of the sulphides introduces such difficulties in obtaining positively uncontaminated samples that it was felt better in the present investigation to hold to coarse-grained examples from well-known districts.

[5] The authors have no first-hand knowledge of the deposit at Edwards, N. Y., and therefore prefer not to try to locate it precisely in the depth-intensity range.

[6] Mineral Deposits, 4th ed., pp. 641 and 739, 1933.

of chemical elements to be expected therein. Viewed from this standpoint, the differences in chemical content of the sphalerites are illuminating. It would be expected that there would be more Ag in the upper mesothermal and leptothermal specimens of group *A* than in those of either less intense (group *B*) or of more intense (Franklin Furnace) conditions of formation; this seems actually to be the case. It would be expected that there would be more Sn in group *A* [7] than in group *B*. This, likewise, appears to be true. It might be expected that group *A* would have more Cu than group *B*. The data do not appear to support that expectation, for Cu is about equal in groups *A* and *B*. But it is to be recalled that many sphalerites of undoubtedly hydrothermal origin show exsolution of Cu as chalcopyrite, while those from the Mississippi Valley type rarely if ever disclose this phenomenon.[8] Since in the samples chosen for analysis under group *A* there was no exsolved excess of copper as chalcopyrite, these particular sphalerites may be regarded as probably lower in Cu than the *average* sphalerite (before any exsolution) for the corresponding position on the depth-intensity scale. Thus the theoretical expectation seems to be again borne out. The probable high-intensity character of the Franklin Furnace ores, however, was inimical to deposition of much copper or of any lead whatsoever; this is also consistent with theory.

With respect to the elements Cd, Ga, Ge and In, so little is known as to the manner in which they may occur in ores and as to the stability relations of such occurrence, that inferences of genetic significance must be drawn with caution. Nevertheless

[7] By analogous reasoning, still more Sn might, perhaps, be expected in the specimen from Franklin Furnace, if that is to be accepted as a high-intensity deposit. But, in the first place, it is probably too much to ask that every district and every specimen therefrom shall in all respects run absolutely true to the general predictions. And, in the second place, there is growing indication that although Sn favors a high-intensity environment with respect to *temperature*, this is not true (at least, not necessarily true) with respect to *pressure*, *i.e.* depth from surface; therefore, if Franklin Furnace does, in fact, represent a very deep-seated deposit, Sn deposition might not be favored in it, even though the solutions from which it was formed may have carried that metal.

[8] See Teas, L. P.: Trans. Amer. Inst. Min. Eng., vol. 59, pp. 68–82, 1918.

some tentative generalizations may be set down.[9] *Cadmium* occurs as the independent mineral greenockite, which is known both in undoubted hydrothermal deposits (*e.g.* Przibram) and in deposits of the Mississippi Valley type. This mineral has been regarded by some observers as a "secondary" (probably supergene is meant) sulphide, but the evidence in support of that view as distinguished from mere lateness in the sulphide sequence does not appear to be very convincing as yet. Cadmium occurs also as przibramite, a notably cadmiferous sphalerite or wurtzite, and as otavite, a basic cadmium carbonate resulting from sulphide ore oxidation; both these minerals come from regions of hydrothermal ores. Cadmium oxide has also been reported as a coating on hemimorphite.[10] The element is contained in smaller quantities in many sphalerites, and in some oxidation products thereof; also in wurtzite. Extremely minute quantities have been detected spectrographically in apatite and in biotite of igneous rocks of Odenwald,[11] Germany. The intimate association of Cd with Zn is indicated not only by the fact that it is the next heavier immediate relative in the periodic table, with all the close chemical resemblances that this implies, but also by the peculiarity that whereas all the other metals known to crystallize in the hexagonal close-packed arrangement have the $c:a$ ratio of lattice parameters approximating 1.63, the corresponding axial ratio for Zn is about 1.86, and for Cd about 1.89.[12]

No systematic survey of the geochemistry of Cd has yet been made; and adequate data for even a respectable beginning prob-

[9] Although these four elements have long been regarded as especially associated with Zn, spectrographic studies in recent years have shown their wide distribution in many minerals and rocks, not infrequently in quantities quite comparable with what is found in sphalerites. It may be inferred that these rare elements were most easily detected in association with Zn because of the distillation process by which Zn is recovered from its ores and the favorable opportunity thus occasioned for a highly selective concentration of minute components. For this same reason, Zn ores may still be the most practical metallurgical source of these rare elements without necessarily representing their richest natural concentrations.

[10] Cadmium, p. 4, Imperial Institute, London, 1929.

[11] Schröeder, F.: Neues Jahrb. f. Min. Beil Bd. 63, p. 257.

[12] Wyckoff, R. W. G.: The Structure of Crystals, p. 201. 2d Ed., New York, 1930.

ably do not yet exist. As regards the Cd-content of sphalerites, it is probably safe to assume, where careful microscopical examination has failed to disclose the presence of an independent Cd mineral (*e.g.* greenockite), that the Cd disclosed by analytical or spectrographic means is present in solid solution. This presumption is strongly favored by the dimensional similarities of the unit cells of sphalerite and of isometric CdS (known synthetically) and of the corresponding unit cells of wurtzite and of greenockite, as shown below, when considered in the light of Goldschmidt's rule [13] that isomorphism is permissible when the size of the units differs by less than 15 per cent. of the smaller one.

LATTICE PARAMETERS OF ZnS AND CdS.[14]

(In Ångstrom Units.)

	Isometric	Hexagonal	
ZnS.....	5.43	*a* 3.84	*c* 6.28
CdS.....	5.82	*a* 4.14	*c* 6.72

The general indications from such data as are available seem to be that Cd is rarely fixed under orthotectic conditions, and that it tends also to avoid the more intense phases of hydrothermal deposition, while depositing mainly in occurrences of lower physico-chemical intensity. Hintze records that the Cd content appears to be higher in wurtzites than in sphalerites; this is probably consistent with what has just been said, since sphalerite is stable in ores formed under much more intense physico-chemical conditions than those in which wurtzite occurs. On the other hand, it is reported that the Cd: Zn ratio is higher in the Kentucky-Illinois fluorite deposits than in the deposits of the Tri-State region; if this is a consequence of conditions governing precipitation rather than merely the result of a difference in initial proportions of Cd in the source-material for the two sets of deposits, it would suggest that the apex of Cd deposition comes before the conditions for sulphide deposition have reached their feeblest state, since the

[13] Geochemische Verteilungsgesetze der Elemente, VII, p. 83, 1926.

[14] Wyckoff, *op. cit.*, pp. 225 and 229.

Kentucky-Illinois deposits, now generally accepted as hydrothermal, are to be regarded as formed under somewhat more intense conditions (perhaps because better localized and less dissipated) than were the deposits in Missouri and Oklahoma. The assertion that the minerals of oxidized Zn deposits are richer in Cd than are the corresponding sulphide portions,[15] if truly of general validity, may be merely a consequence of different solubilities of CdS and ZnS under oxidizing conditions.

The relative quantities of Cd shown in Fig. 1 for the three groups of deposits conform with the general tendencies discussed just above, in that the Cd content increases with decreasing intensity-character of the deposits.

Gallium forms no known natural mineral, and occurs only as a minute component in other minerals. Its widespread occurrence in sphalerite has been demonstrated spectrographically by Papish and Stilson,[16] and its presence in a great number of minerals has similarly been proved by Goldschmidt and Peters.[17] The close relation of Ga to Al in the periodic table is confirmed by the intimate natural association of Ga to aluminous minerals and rocks. From Goldschmidt and Peters' findings it appears that the Ga-content increases in the course of rock differentiation from ultrabasic to acidic and alkalic phases, which likewise corresponds in a general way to rising Al-content; the increase in Ga continues notably in the pegmatites, and especially in those approaching hydrothermal characteristics (except for the minerals of the cryolite group, mentioned later); by the time the late and feeble hydrothermal stage of zeolite formation has been reached, deposition of Ga in the silicate minerals has strongly decreased in the normal alkali-lime rock series, but has been maintained or even increased in the Al-rich alkali rocks; siliceous deposits from hot springs in geyser regions, while for the most part not notably high in Ga, contain strikingly more of the element than do

[15] Juretzka, F.: Metall. u. Erz., vol. 12, p. 235, 1915; also Budgen, N. F.: Cadmium, p. 2, London, 1924.

[16] Amer. Min., vol. 15, pp. 521–527, 1930.

[17] Goldschmidt, V. M. and Peters, C.: Zur Geochemie des Galliums. Gesell. Wiss. Göttingen, pp. 165–183, 1931.

siliceous deposits presumably of " cold-water " origin. The finding by Papish and Stilson of Ga in all specimens of gahnite examined indicates a two-fold allegiance of the element: to Al and to Zn. Papish's finding of noteworthy Ga in lepidolite is in line with the conclusions of Goldschmidt and Peters just mentioned.

Unfortunately, because of the ground already covered by Papish and Stilson with regard to sphalerite, Goldschmidt and Peters did not make a general survey of the sulphide minerals; they report absence or virtual absence of Ga in a few marcasites and tetrahedrites: but they do show that sphalerite of the Ivigtut occurrence carries much more Ga than the Al-rich cryolite of the same occurrence. This last relationship not only is in accord with the conclusion of Goldschmidt and Peters that Ga is more strongly chalcophile and siderophile than is Al, but it further suggests that the affinity of Ga is greater for the sulphide minerals than for the aluminous minerals, and thus perhaps explains why the cryolite minerals associated with sulphides, although themselves rich in Al, are poorer in Ga than are pegmatites that carry no sulphides (see above).

From the indicated quantitative relationships of Papish and Stilson's examinations of many sphalerites may be deduced the interesting fact that the well known high-intensity examples of sphalerite:—Sullivan Mine, Kimberly, B. C.; Success Mine, Coeur d'Alene, Idaho; Hanover, N. M.; Franklin Furnace, N. J.; Cornwall, England, and Bottino, Italy, all show very faint traces of Ga, as contrasted with the sphalerites of lower-intensity conditions of formation. They found no Ga whatever in the common oxidation products of sphalerite, namely, calamine, smithsonite, hydrozincite and gosslarite. This is the opposite of the behavior of Cd under like circumstances, and emphasizes the improbability of simultaneous accumulation of those two elements under supergene or " meteoric " conditions.

The isomorphism of bivalent Cd in the sulphide of bivalent Zn raises no obvious difficulty, as already discussed. To account, however, for the apparent preference of trivalent Ga for sphalerite rather than for other sulphides, Goldschmidt and Peters make the

interesting suggestion [18] that the element occurs as GaAs, which in synthetic preparations Goldschmidt had found to have the same structural arrangement as sphalerite and closely similar lattice dimensions (ZnS = 5.418 Å and GaAs = 5.635 Å), so that isomorphism would be readily possible. That As is actually present (and in sufficient proportion) in all these Ga-bearing sphalerites apparently has not yet been established.

For present purposes, the general available data suggest that Ga tends to concentrate with Al from the earliest stages of magmatic differentiation until those stages are reached where sulphide-deposition appears, and that thereafter the Ga tends to desert such Al minerals as are then formed in favor of ZnS; furthermore, that the higher-temperature occurrences of sphalerite contain less Ga than those of lower-intensity origin. The oxidation products of sphalerite definitely lose Ga, the direct opposite of the indications for Cd.

In the present samples, as summarized in Fig. 1, it will be seen that the average Ga-content for the three types of occurrences conforms with the expectations based on general physico-chemical and geochemical grounds. Our specimen from Franklin Furnace shows no Ga whatsoever.

Germanium occurs as an essential component of the minerals argyrodite, canfieldite and germanite, as well as in small to minute quantities in a variety of other minerals, including sphalerite, enargite, pyrargyrite, stannite, franckeite, cassiterite and native copper among the ore minerals and notably topaz, tourmaline, spodumene and lepidolite among the silicates.[19] The characteristics of the metal as a lighter relative of bivalent-quadrivalent Sn are shown in its presence in the tin minerals, especially its isomorphous association with Sn in canfieldite. Its linkage with quadrivalent Si, of which it is a heavier relative in the periodic table, is revealed by its rather noteworthy presence in many silicates and by numerous analogies of synthetic Ge-compounds with

[18] *Idem.*, p. 181.

[19] Papish, J.: New Occurrences of Germanium. Econ. Geol., vol. 23, pp. 660–670, 1928, and vol. 24, pp. 470–480, 1929; Goldschmidt, V. M. and Peters, C.: Zur Geochemie des Germaniums, nachr. Gesell. Wiss. Göttingen, pp. 141–166, 1933.

corresponding Si-minerals. The special quantities of Ge found in topaz, tourmaline, spodumene and lepidolite speak for its stability under pneumotectic conditions. But among the sulphides it appears more at home from the shallower mesothermal zone upward; enargite, argyrodite, pyrargyrite and sphalerite appear to be its chief hosts. As Papish and Stilson's results indicate for Ga, so Goldschmidt and Peters conclude for Ge, that the hydrothermal sphalerites are richer than those of pyrometasomatic origin. They also find that the sphalerites and wurtzites of lower-intensity conditions of formation have higher Ge-content than do those of the deeper hydrothermal zones. Finally, they come to the very significant finding that there is decidedly more Ge in hydrothermal sinters than in siliceous deposits by vadose waters. As to the manner of occurrence of Ge in sphalerite, Goldschmidt and Peters suggest either its presence as solid solution of GeS or as an atomic dispersion of Ge.

Once more our own results show general coincidence with prior findings: the Ge-content increases with declining intensity-character of the deposits.

Indium, next heavier relative of Ga in the periodic table, is less well investigated as to occurrence than the other three rare metals already discussed. No independent In mineral is known. The element is found in Fe and Mn ores, also in ores of Sn and W, as well as in sphalerites. It would be expected that In would show associations generally parallel to those for Ga, and so far as known this seems to be true, but the data are as yet too meager to be very illuminating. Goldschmidt, Barth and Lunge [20] express the belief that In probably occurs in sphalerite in the bivalent form. This would not correspond with the view already mentioned that Ga occurs as solid solution of GaAs.

Our own results (Fig. 1) show that In is the only one of these four metals in which the relative quantities are not inversely proportional to the indicated physico-chemical intensity of the deposits. Here, the quantity of In found in the specimen from Franklin Furnace puts the average for group *C* slightly highest

[20] Geochemische Verteilungsgesetze der Elemente, V., p. 57, 1925.

of the three. Whether this is an accidental or erratic result which would disappear if many more examples were investigated, or is really an indication of a departure of In from the general rule for Cd, Ga and Ge, cannot at present be determined. The relative quantities in In for groups *A* and *B* conform to the same tendency as shown for all groups by Cd, Ga and Ge.

Summation.

The foregoing analysis indicates not only that the various subordinate constituents of the sphalerites of all three broad groups or occurrence-types show striking correspondences, but also that the actual divergences from exact correspondence or identity of content are almost invariably of the kind and in the direction that would be predicted from the known geochemistry of each of these subordinate elements. This situation is nowhere more striking than in the case of those four special friends of sphalerite, namely Cd, Ga, Ge and In, where, with the single exception of the In-content of group *C*, the relative proportions of these elements correspond with the expectations to be drawn from the best data now known.

Taken as they stand, the data strongly indicate that the sphalerites of group *B*, those of the Mississippi Valley type, stand in a definite and systematic serial relationship to the hydrothermal sphalerites of group *A*.[21] The nature of this serial relationship appears to be entirely analogous to the numerous serial relationships exhibited within the general hydrothermal family which justify the subdivision of that family into the so-called zones, such as hypothermal, mesothermal, etc. Is it merely a coincidence that the deposits which many geologists now group as belonging to the telemagmatic category or telethermal zone are found, in this further particular of the subordinate metal-content of their sphalerites, to show just what they would be expected to show if they were, indeed, the feeblest representative of the hydrothermal family?

[21] The probability that group *C* stands in a corresponding serial relationship on the higher-intensity side of group *A* is suggestively indicated. But we do not wish to press that inference unduly on the basis of such restricted data.

It is fully appreciated that these indications, inferences and arguments cannot be conclusive and compelling. To make them so, far more study and a much greater accumulation of precise data would be needed. But it is submitted that the situation as it stands is so strongly presumptive that unless better proof than at present available shall be brought forth for non-magmatic, non-hydrothermal ancestry of the Mississippi Valley type of deposits, the telethermal character of these deposits must gain the verdict.

COLLATERAL EVIDENCE.

Each item of presumptive evidence favoring any given conclusion gains dignity and impressiveness as it is supported by, and in turn supports, other items of presumptive evidence of the same import. Like "circumstantial evidence" in law, a single piece, standing by itself, may be entitled to relatively little weight, but sufficient accumulation of pieces, all pointing similarly, at last becomes overpowering. It may therefore be pertinent, while by no means attempting a comprehensive analysis of the origin of the Mississippi Valley ores, to refer briefly to a few of the other items of minero-chemical or closely related evidence that bear on that question.

Mineral Association.

To the significance of the long-standing recognition that galena and sphalerite tend to favor the low-intensity fringes of hydrothermal and pyrometasomatic ores may be added the growing indication that marcasite, so common in these ores of Mississippi Valley type, is also a component of near-surface deposits from magma-derived solutions. Ores of the Mississippi Valley type contain barite, linnaeite (and other Ni and Co minerals), jordanite, enargite [22] (recently reported) and, in the oxidized ore, wulfenite.[23] The galena from Joplin, as well as galena, sphalerite

[22] McKnight, E. T.: ECON. GEOL., vol. 30, pp. 61–66, 1935.

[23] Also reported by McKnight, *Idem.* This wulfenite is probably to be regarded as a product of concentration, during the oxidizing process, of Mo that had been contained in the galena; it would thus be entirely analogous to the development of Pb compounds of Cr, Mo, P, V nad W derived in the oxidized portions of hydro-

and pyrite from definitely hydrothermal localities, has recently been shown to contain small quantities of Cr, Mo, V and W.[24] The presence of these components of the Mississippi Valley ores will need more effective explaining than has yet been given to dispose of the probability that these several minerals and elements represent normal continuations from deeper hydrothermal zones into the telemagmatic or telethermal deposits. Moreover, it is impossible to ignore the close similarities between the ores commonly grouped together as Mississippi Valley type and (limestone) ores in which cinnabar and fluorite suggest still more strongly their magmatic parentage.

Character of Silica.

There are striking resemblances in textural detail between the fine-grained ore-bearing " jasperoid " of the Tri-State region and the cryptocrystalline silica of some of the shallowest-seated epithermal veins in lavas, such as those of Mogollon, New Mexico, and Republic, Washington.

Exsolved Chalcopyrite.

It will be recalled that Teas [25] concluded from his finding of chalcopyrite inclusions, as " dots and stringers," in many sphalerites of admitted magmatic derivation and his failure to find them in sphalerites (including those of the Mississippi Valley type) which he accepted as of " meteoric " origin, that the absence of such inclusions in any sphalerite was therefore to be taken as presumptive evidence of its deposition from surface waters. Teas's data show that there is a tendency for these inclusions to decrease in number and importance with declining intensity of the conditions of deposition, his notation for the shal-

thermal ores, in which these less common elements have been traced to the hypogene minerals. See following footnote.

[24] Newhouse, W. H.: Amer. Miner., vol. 19, pp. 209–220, 1934. The presence of Mo and V in galena from several hydrothermal deposits in the western United States, where oxidized Mo and V compounds of Pb occur, has also been proved spectrographically by H. H. Chen (Doctor's Thesis, Harvard University, 1927).

[25] *Op. cit.*

low-vein zone being "small, few" (as contrasted to "fairly numerous" to "very numerous" for the deeper, more intense zones). But he failed to suggest that if this tendency should continue to hold in deposits of similar source but of still feebler intensity-conditions of deposition, there might be little or no chalcopyrite as inclusions in the sphalerites of such feeblest hydrothermal zone. In the discussion of Teas's paper, however, the fact was recorded [26] that, in regions of hydrothermal zoning, sphalerite from more central positions may hold these chalcopyrite inclusions whereas sphalerite peripherally located may contain none; in other words, the presence or absence of the inclusions is not a criterion of magmatic or "meteoric" origin, respectively, but might for all cases, as Teas had shown for some, be no more than an expression of the conditions under which deposition from the magma-derived solutions had taken place.

It is now evident that these characteristic inclusions of chalcopyrite in sphalerite mainly represent exsolution units from the sphalerite (carrying Cu and Fe in solid solution) as initially deposited. Experience and analogy indicate that the higher the temperature of deposition of the sphalerite, the greater is the chance of its incorporating Cu and Fe as solid-solution components; and it is obvious that the higher the temperature of deposition of such solid solution, the greater is the likelihood of exsolution of chalcopyrite on cooling down to the temperature of present-day occurrence.

In short, the scantiness or absence of exsolved chalcopyrite in sphalerite of ores from the Mississippi Valley type of occurrences, instead of implying a different and special kind of genesis, *i.e.*, by meteoric waters, is rather an indication of its low-intensity (telethermal) conditions of formation, and affords presumptive evidence of its analogy with the similarly chalcopyrite-free sphalerite present on the outskirts of deposits unquestionably of magmatic derivation.

[26] Teas, L. P.: *op. cit.*, pp. 85–86.

Color and Iron Content.

In numerous districts of hydrothermal occurrence, the sphalerite near the margins of individual ore bodies or of the mineralized area as a whole is of lighter color and purer (*i.e.* lower in Fe) than that more centrally located. In certain high-intensity occurrences, there was so much Fe present in the sphalerite as initially deposited that a part exsolved as pyrrhotite quite analogous in forms and manner of distribution to the exsolved chalcopyrite. In a rough and general way, then, iron content in admittedly magma-derived sphalerite appears to correspond with the intensity of conditions of mineral deposition.

As contrasted with other sphalerite, that from deposits of the Mississipp Valley type is rarely iron-rich and is in many places conspicuously light colored. So far as known, no Fe has exsolved from it, either as pyrrhotite or chalcopyrite. Moreover, in the Mississippi Valley metallogenetic province considered as a whole, there seems to be a suggestion of the same tendency toward somewhat darker sphalerite centrally and lighter sphalerite in out-lying regions that is seen in regions of unquestioned hydrothermal zoning. The probability that these similar results are consequences of wholly unlike processes of accumulation and deposition seems very much smaller than that they are common manifestations of a common genesis.

Composition and Behavior of Fluid Inclusions.

Perhaps most significant of all is the recent information derived from fluid inclusions in galena and sphalerite. Newhouse concluded [27] that the high concentrations of NaCl brine which he (and earlier Buerger [28]) had found in galena, whether from the Mississippi Valley or from admittedly hydrothermal districts,

[27] ECON. GEOL., vol. 27, pp. 431, 432, 435–436, 1932. As W. A. Tarr points out (ECON. GEOL., vol. 28, p. 477, 1933), such high concentration may not be representative of the depositing solution as a whole. But in any case, the similarity of brine composition in all the samples is in itself presumptive evidence of their closely-related genesis.

[28] Buerger, M. J.: Amer. Miner., vol. 17, p. 228, 1932.

could probably come only from magmatic extracts. Newhouse, having further found that gas-bubbles in liquid inclusions in sphalerite disappear when heated, concluded [29] that the temperature of disappearance represents approximately the temperature at which the sphalerite was formed. For sphalerites from various parts of the Mississippi Valley he finds temperature ranges of 70°–135° C. It may be wise to accept with some reservation the underlying premise that Newhouse adopts until there shall be positive confirmation on synthetic material of known temperature of crystallization that bubble-disappearance occurs at substantially that same temperature. But the temperatures which Newhouse actually finds for Mississippi Valley sphalerites, when measured by the scale of other data, seem so reasonable [30] for telethermal deposits as to be worthy of acceptance as presumptively correct. Moreover, Newhouse found the corresponding temperature to be 145–150° for Rabenstein in the Tyrol, where polybasite and fluorite are present; 145–160° for Santander, Spain, where cinnabar accompanies the sphalerite; 180–190° for sphalerite from Schemnitz, Hungary, where accompanying adularia, fluorite, barite, rhodochrosite, and rhodonite, suggest a genetic position near the boundary between the epithermal and the leptothermal zones. These temperatures, likewise, appear to be of the general order and approximate relationship to one another that would be expected in the several hydrothermal occurrences represented.

These temperature findings, therefore, while not absolutely compelling, are highly significant and impressive. They seem to load a further heavy burden of proof on those who would have the Mississippi Valley type of ores formed from circulating ground waters and who would set up fundamental genetic distinctions between these deposits and those admittedly formed directly by magmatic agencies.

[29] Newhouse, W. H.: ECON. GEOL., vol. 28, p. 744 et seq., 1933.
[30] Cf. Graton, L. C.: ECON. GEOL., vol. 28, p. 554, 1933.

CONCLUSION.

What geologists choose to call "proof" of the genesis of a given deposit or type of deposit is, in the present state of geological science, a very different kind of thing from proof of a theorem in geometry or of arsenic poisoning. Ordinarily, geological proof consists of a progressive assembly and weighing of more or less contradictory (because incompletely understood) indications until the accumulations in one scale pan so obviously outbalance the total of opposite character that a majority of those competent to judge finally accept the "weight of evidence" and adopt the view thus favored.

By such a definition, it is here assumed that the origin of the Mississippi Valley type of lead-zinc deposit is not yet proved. The authors of the present paper are under no delusion that with their final page this situation has been changed. They have merely sought to add perhaps a few more spectrographic straws to the magmatic scale pan and to help emphasize the importance of some of the other weights it had already received. The scope of argument here employed is obviously restricted; the matters considered embrace only certain details of mineral chemistry limited mainly to sphalerite, and no part of that great array of pertinent fact dealing with rock character, structural relations and timing has been even touched upon.

It is hardly to be expected with respect to this long-standing controversy that a shift of opinion will come abruptly or on the basis of any single disclosure. The present writers undertake to go no further than to emphasize their conviction that the protagonists of a "meteoric" origin for the Mississippi Valley ores and similar deposits are faced by a real task to offset the weight of the accumulating evidences—evidences which oppose the hypothesis that these low-intensity sulphide ores are unique and apart from epigenetic sulphides as a whole, but on the contrary, point to existence of a direct serial relationship between these particular shallow ores and those now firmly established as members of the magma-derived hydrothermal family. It is to be hoped that

the meteorists will recognize and accept the challenge which these several recent lines of evidence constitute. The trend of petrologic theory and of metallogenetic understanding, furthered by world-wide observation and by intensive experimentation, appears to be setting strongly against them. In the United States, they have long held the majority vote. How long can they keep it? Do they have it still?

LABORATORY OF MINING GEOLOGY,
HARVARD UNIVERSITY,
April 3, 1935.

DISCUSSION AND COMMUNICATIONS

PETROGRAPHY OF FULLER'S EARTH DEPOSITS.

Sir:—In a recent issue of this Journal,[1] a communication from E. F. Newton questioned my determination of a sample of fuller's earth from near Bath, England, as bentonite. The paper[2] in which this determination was presented was particularly concerned with fuller's earth from Illinois. Brief discussions of the essential mineral constituents and textures of other fuller's earths were included for comparison. A paragraph was inserted concerning a sample of earth from near Bath, England, which I had obtained from L. A. Salomon and Bros., Importers, New York City, who stated that the sample supplied by them was from this locality and was unwashed and not processed, although they believed that it was selected. Obviously, I cannot certify to the location of this sample; however, the importers verified their original statement in a letter dated December 19, 1934.

My statement was as follows:

> English Fuller's Earth from near Bath.—This material is composed of 95 per cent. montmorillonite ($\gamma = 1.502$; $\gamma - \alpha = .021$; (—); 2V small) and 5 per cent. quartz, orthoclase, and amphibole, in fragments with maximum diameters of 0.06 mm. The montmorillonite occurs in crystalline particles varying to 0.1 mm. in size. The shape of the smaller ones can not be determined, but the larger ones are flaky and show little uniformity of orientation. Orthoclase and amphibole show some alteration to montmorillonite. Glass shards are also present and are excellently preserved. Pseudomorphs of montmorillonite after glass fragments are also perfectly preserved. The earth can be designated as a bentonite.

[1] Newton, E. F.: ECON. GEOL., vol. XXIX, pp. 307–308.

[2] Grim, R. E.: Petrography of the Fuller's Earth Deposits, Olmstead, Illinois, with a Brief Study of Some Non-Illinois Earths. ECON. GEOL., vol. 28, pp. 344–363, 1933.

Concerning this statement Mr. Newton states:—"Actually what appear at first sight to be glass shards in thin sections of the Bath fuller's earth are platy and angular fragments of a mineral with glassy appearance and low birefringence which can be concentrated in considerable quantity by carefully washing the material. Chemical analyses show this material to be a variety of feldspar-anorthoclase with a small proportion of lime."

Since the fragments that were designated in my paper as glass shards are isotropic with $\eta = 1.48 \pm$, whereas anorthoclase is biaxial, (—), $\gamma = 1.527$, $\gamma - \alpha = .008$ as stated by Larsen and Berman,[3] they cannot possibly be anorthoclase. These fragments can be washed out of the earth and their index of refraction measured. They are not platy. Their identification as shards was based on the correspondence of their optical characteristics with those of volcanic glass, and their concave shape. The presence of this material and the fact that thin sections of the earth show many montmorillonite pseudomorphs after shards appear to be positive evidence that the sample studied is bentonitic.

Newton states further:—"The mineralogical description of the fuller's earth of Bath is of more interest than Mr. Grim indicates. The material contains abundant sphalerite, much of which shows excellent crystal form and occurs in grains up to 0.1 mm. across. Marcasite also is common, often associated with calcite, filling the tests of foraminifera." In my paper no attempt was made to give a complete notation of the minerals present in the Bath earth studied—the objective being to show that montmorillonite was the essential constituent and that textural characteristics indicated it to be a bentonite. However, in my sample, sulphides are extremely rare, calcite is not common, and careful search has revealed an absence of foraminifera.

On reading Newton's communication, it occurred to me that we may have studied different material from the Bath area. Mr. Newton has kindly sent to me two samples of his fuller's earth from this region. One of these samples is green and possesses the same general appearance as my sample. It differs from it,

[3] Larsen, E. S., and Berman, H.: U. S. Geol. Survey, Bull. 848, 1934.

however, in being highly calcareous. No shards or relict structures could be found, but the abundance of calcite could easily conceal such structures in the thin sections studied. The other sample is brown, containing much limonitic material which tends to conceal textural details. In this sample no glass shards could be found and no clay mineral pseudomorphs after shards could be detected.

A sample of the earth obtained from L. A. Salomon and Bros. was sent to Newton, who states, in a letter dated October 11, 1934, regarding this material, that he has been "unable to trace what you mean by glass shards by any means of investigation used." I found, in washed portions of this same material, fragments which show no evidence of anisotropism and possess an index of refraction of about 1.49. Some of them exhibit shapes characteristic of shards, and this, together with the similarity of their index of refraction and that of volcanic glass, warrants the conclusion that they are glass shards (Fig. 1).

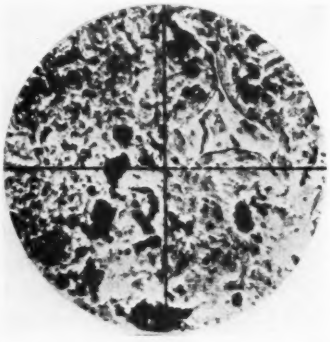

FIG. 1. English fuller's earth, from vicinity of Bath. Sample from L. A. Salomon and Bro., Importers, New York City. × 500.

Fragment (*A*) of glass showing shape characteristic of many shards in this material. The dark patches inside of the shard are chiefly the result of diffraction, a phenomenon commonly found in photomicrography where high magnification is used. Under the microscope, particularly with lower magnification, this fragment is uniformly clear and transparent.

Newton states further concerning the sample sent to him:—"Other patches in thin section which seem at first to be isotropic, polarize in very low order colors, and when these are isolated so that the grains have not suffered any loss of thickness by grinding, they prove to be a definite mineral species with a low birefringence. The refractive index is about 1.49. These grains cannot be glass, although the polarization sometimes shows a strain shadow." Many of the shards are partially or completely altered to montmorillonite, hence the earth does contain many fragments with an index of refraction of about 1.49 which possess a slight anistropism. Evidence that these fragments are partially altered shards is very clear from thin-section examination, which shows that many of them have retained the characteristic shape of shards, like that shown in Fig. 1.

Newton states that the samples sent to him contain "a certain amount of isotropic material of a somewhat angular nature observable in thin section, but when these grains are isolated they prove to be sponge spicules and small circular and spherical organisms now composed of opal; refractive index about 1.43." I have observed a very few of these grains but they should not be confused with the other isotropic fragments with the higher refractive index which have been classed as glass shards.

Since the samples sent to me by Newton contain no positive evidence of a bentonitic origin, whereas my sample presented such evidence, it seems probable to me that the formation as exposed in the Bath area contains certain layers which show evidence of a bentonitic origin. This explanation was suggested to Newton, who replied: "When I visited the workings the material appeared to be quite homogeneous, except where it was definitely separated in the middle by a more calcareous band." This possibility can be proven or eliminated, however, only by a detailed investigation of the workings.

Newton states further:—"The specimen you sent me produced, in the crop of minerals sinking in bromoform, one or two I have never before seen in Bath earth, and in this respect the specimen does not seem at all typical. Is it possible that the

importer has given you the wrong locality for this rock?" The importers[4] checked the locality as correct, although the possibility of its being incorrect cannot be eliminated entirely. It appears likely that beds of bentonitic material might well possess a few heavy minerals not present in the overlying or underlying beds, if the latter are not bentonitic and have had a different source.

Newton questions also my identification of the mineral montmorillonite in the Olmstead, Illinois, fuller's earth. This determination was based (*a*) on the identity of the X-ray diffraction pattern of type montmorillonite from Montmorillon, France, and the mineral in the Olmstead earth; (*b*) on the agreement of optical values of this mineral with similar published values for montmorillonite; (*c*) on the agreement of dehydration characteristics of this mineral with similar published values for montmorillonite; and (*d*) on the similarity of the chemical composition of this mineral with published analyses of montmorillonite. An identification based on one of these characteristics would probably not be entirely trustworthy, but the agreement of all of them permits a positive identification.

Newton states further:—"It is possible that kaolinite and other clay minerals might be 'proved' by similar evidence to be montmorillonite." The separate identity of the kaolin minerals and montmorillonite has, of course, been well established in recent years, and their X-ray, optical, and chemical characteristics are fairly well known. Newton's statement is in effect a charge against the validity of these criteria. RALPH E. GRIM.

ILLINOIS STATE GEOLOGICAL SURVEY,
URBANA, ILL.,
May 9, 1935.

VEIN FORMATION AT PORCUPINE, ONTARIO.

Sir: In his article published in this journal under the above title[1] (vol. 30, no. 2, pp. 103–127), Dr. M. E. Hurst, on the question of origin, comes out strongly in favor of the filling of open spaces as opposed to replacement. I have also seen some

[4] Letter from L. A. Salomon & Bros., Dec. 19, 1934.
[1] ECON. GEOL., vol. 30, pp. 103–127.

of these deposits, and it appears to me that much of the evidence adduced in favor of fissure filling could be equally well used in support of a replacement origin; also, the photographs and diagrams which illustrate the article do not, in my opinion, lend much support to this contention. One in particular may be mentioned, namely, Fig. 3, p. 117, showing an 'S' or hook-shaped quartz vein on the 2000-foot level of the Hollinger mine. Just how such a peculiar structure could have resulted from the filling of an open fissure is certainly not clear to me, but it can be readily explained on the basis of replacement.

Openings of appreciable size in the earth's crust appear to be mainly confined either to calcareous rocks, where they are obviously formed by meteoric waters, or to veins of the epithermal or 'shallow' type. The delicate wavy banding and large, open, drusy cavities characteristic of this class of deposits may be due in part to the filling of open spaces but can also be explained as replacement by colloidal silica gels,[2] or as a case in which solution of the host rock takes place faster than deposition of the vein matter, resulting in unfilled openings or "vugs" in the vein.

The principal objection to the open fissure theory, in my opinion, is the fact that apart from the instances above mentioned, occasional small vugs in other types of veins and miarolitic cavities in igneous rocks, openings of sensible dimensions in rocks below the surface are practically unknown in nature. Mining operations cross innumerable unmineralized fissures and frequently explore faults for hundreds of feet, and if there is any validity in the open fissure theory, some evidence for it should be found. However, the contrary is the case; rarely or never do these unmineralized fissures disclose open spaces; they consist either of tight seams or, in the case of faults, are closely filled with broken rock and gouge. Inasmuch as all partings in rocks are due to the same agencies, and as all mineral veins follow the courses of originally unmineralized fissures, the balance of probabilities weighs strongly against the open space theory and in my judgment it plays a very minor part, if any, in the formation of such ore deposits.

J. A. REID.

TORONTO, CANADA.

[2] Lindgren, W.: Mineral Deposits, p. 181, 1919.

REVIEWS

Geology of Natural Gas: A Symposium. Edited by HENRY A. LEY. Pp. 1227, figs. 259. Cloth, 9″ × 6″. Amer. Assoc. Petrol. Geol. Tulsa, Oklahoma, 1935. Price, $6.00.

This excellent volume consists of a symposium of thirty-eight papers prepared by forty-seven authors, under the able editorship of Henry A. Ley. To quote from the subtitle, "Here for the first time has been assembled a comprehensive geologic treatise of the occurrence of natural gas on the North American continent."

The question which obtrudes itself almost from the moment one glimpses the title is that of what may be the geological characteristics which distinguish natural gas deposits from petroleum deposits. The editor anticipates this question in the second paragraph of his foreword with the statement that:—"In most respects the geology of natural gas is fundamentally the same as the geology of petroleum." Further development of this problem as touched by various authors in the course of the work serves rather to accentuate the fundamental similarity than to develop the differences. What causes only gas to occur "without associated oil, on a structure, in a reservoir, or in a far-reaching area"? This different phase of the same problem or perhaps the fundamental problem itself, of which the first question is but a phase, is also considered by the editor in his foreword. He notes areas of gas occurrence and theories proposed in explanation, and surmises that "there is probably no one theory which satisfactorily explains all conditions in any one area." These theories branch out into the debated fields of origin, migration, and metamorphosis, and can hardly be entirely satisfactory while based on such uncertain foundations. One is left with his own conclusion that about the only tangible exception to the "in most respects" in which the geology of natural gas is fundamentally the same as the geology of petroleum, is that in the one case oil and gas occur in initimate association; in the other case, gas alone occurs.

The symposium, indeed, concerns itself so essentially with oil-field structure that it might well have been presented as the third volume of the Association's "Structure of Typical American Oil Fields" with a sub-title calling attention to the emphasis on gas.

All of the material is here first presented with the exception of Cotner and Crum, "Geology and Occurrence of Natural Gas in Amarillo Dis-

trict," and Gordon, "Richland Gas Field," both of which are reprinted from the Bulletin of the Association. It was originally intended to extend the scope of this work to include gas fields outside of North America, and papers on Australia, Burma, Europe, Germany, India, Poland, Roumania, and Russia have been diverted to the Bulletin and were published in it in 1934.

The first three papers in the volume have to do with gas in Canada, the next thirty with fields in the United States, and the thirty-fourth has to do with gas in Mexico. The symposium concludes with papers on "The Valuation of Gas Properties"; "The Estimation of Natural Gas Reserves"; "The Geology of Natural Gases Rich in Helium, Nitrogen, Carbon Dioxide and Hydrogen Sulphide"; and a treatise in brief on "Natural Gas" by the editor, Mr. Ley.

This volume should have a much broader appeal than its title indicates. For the general geologist interested in North America there is not only much new detail with regard to stratigraphy and structure for special areas but there is also a great deal of summarized information of high quality regarding broad areas. Slipper's discussion and sketch maps on the regional geology of Alberta; Harkness on Ontario; Snider and Farish on Quebec and the Maritime Provinces; Kirkham on Washington, Oregon and Idaho; Cotner and Crum on the Panhandle and Western Kansas; Rettger, Carsey and Morero on the Permian Basin of Texas and New Mexico; Garlough on Western Kansas; Ley on Eastern Kansas; Colton on the Arkansas Basin of Eastern Oklahoma; Croneis on the Interior Highlands of Arkansas; Tomlinson on Southern Oklahoma; Kendrick and Russel on the Bend Arch of Texas; Ley and Willson on the East Texas Embayment; Teas on the Gulf Coast Salt-Dome Area; Newcombe on Michigan; Bell on Illinois, Indiana, and Western Kentucky; Bailey on the Southern Cincinnati Arch Region; Stout, Lamborn, Ring, Gillespie and Lockett on central and eastern Ohio; Hunter on eastern Kentucky; and Torrey on New York and Pennsylvania: each of the foregoing papers contains a sound three, or four—if you please—dimensional regional geological sketch.

The petroleum geologists who is chiefly interested in gas as something usually less desirable than oil and more desirable than a dry hole or salt water, will appreciate greatly the 107-page "Natural Gas Resources of California," by Hoots and Herold, as the most timely and valuable general description of the oil fields of that area available to him. Likewise he will appreciate the 139 pages of papers on "Natural Gas in Montana," by Bartram and Erdmann; "Gas Fields of Big Horn Basin Structural Province, Wyoming and Montana," by Emery; "Billy Creek Gas Field, Johnson County, Wyoming," by Boyer; "Gas Fields of Lost Soldier District, Carbon and Sweetwater Counties, Wyoming," by Tillotson; "Geology of Baxter Basin Gas Fields, Sweetwater County, Wyoming," by

Nightingale; "Geology at Hiawatha Gas Fields, Southwest Wyoming and Northwest Colorado," by Nightingale; and "Natural Gas in Colorado, Northern New Mexico and Utah," by Winchester. Furthermore, the papers on "Natural Gas in West Texas and Southeast New Mexico," by R. E. Rettger, J. Ben Carsey, and J. E. Morero, and "Natural Gas of Gulf Coast Salt-Dome Area," by L. P. Teas, are as important or more important as oil papers than as gas papers.

To the person interested solely or chiefly in earth gases, the entire symposium should appeal. Dobbin's paper on "Geology of Natural Gases Rich in Helium, Carbon Dioxide, and Hydrogen Sulphide," and Muir's paper on "Occurrence of Natural Gas in Mexican Oil Fields, with Notes on Lake Chapala Region and Valley of Mexico," are interesting papers concerned solely with gas.

For the technologist, Eugene A. Stephenson's paper on "Valuation of Natural Gas Properties," and Biddison's paper on "Estimation of Natural Gas Reserves," will be serviceable; and for the less technical reader, Ley's "Natural Gas" furnishes a broad view of the entire natural gas industry.

Among its other excellencies, let us hope that this collection of papers will inspire further efforts to explain the occurrence of natural gas deposits which are not associated with oil.

E. DEGOLYER.

Spezielle Petrographie der Eruptivgesteine. Ein Nomenklatur-Kompendium. By W. E. TRÖGER. Pp. v + 360. Verlag Deutschen Mineralogischen Gesellschaft e.V., Berlin. 1935. Price (paper), 20 RM.

The author has assembled all the data he can find on the quantitative mineralogical and chemical nature of igneous rocks, especially those that are rare, has corrected the errors found in earlier publications, and has classified all igneous rocks rigorously according to their modal and chemical characteristics, using as his foundation the Niggli and the CIPW schemes. All the rare rocks, and those that have been given local names but have not been precisely defined, have been re-examined and re-defined and as a consequence have been placed in their proper niches in the classification. He recognizes 32 rock families and 777 rock-types, characterizing each in detail by giving its modal mineral proportions and, in nearly all cases, its position in the CIPW system. No distinction between types is made on the basis of structure. Under each rock-type there is a list of the names that have been applied to rocks belonging in it. An examination of the index shows 1420 rock names referred to in the body of the text.

A list of 245 synonyms and names of rock groups add to the value of the compendium, as do also three appendices. One of these is a guide to the determination of the rock families. Another is an outline of

Niggli's classification of magma-types with their corresponding formulas in the CIPW classification; and the third is a table of the analyses of significant rock components.

The book is unquestionably of great value to all geologists interested in igneous rocks, because it has gathered in one place the data scattered through many publications, and particularly because of the information it gives about rare rocks and unfamiliar rock names.

W. S. BAYLEY.

Geology and Ore Deposits of the Breckenridge Mining District, Colorado. By T. S. LOVERING. Pp. vi + 64, figs. 28, pls. 15. United States Geol. Survey, Prof. Paper 176. Washington, 1934.

The Breckenridge district was described in detail by Dr. F. L. Ransome in 1911 (U. S. Geol. Survey Prof. Paper 75), but at the time of his studies much of the deeper country recently accessible had not yet been explored. Moreover, Ransome's report covered an area of 45 square miles on the scale of 1: 24,000.

In the report here reviewed the scale has been doubled and far more accurate areal mapping has thus been made possible. Moreover, a greater amount of bed-rock geology has been shown, less of the surface being mapped as alluvium. The increase in scale is consistent with the policy recently followed by the United States Geological Survey for many mining districts, and is eminently desirable from both theoretical and practical standpoints. It has enabled Dr. Lovering to give far more structural detail, and new faults and fissures are shown, with consequent clarification of the general structural pattern.

The excellent and well-known report by Ransome need not be reviewed here, but Lovering's professional paper contrasts with it in certain respects that are of great theoretical interest and therefore deserve mention. One of these is the strong emphasis placed in the later paper on structural controls of ore deposition and the close attention given by its writer to regional as well as local structures. Written by a careful student of Front Range geology, Professional Paper 176 shows the connection between the details observed at Breckenridge and the much larger features characterizing this section of the Rocky Mountains. The ore-bearing rocks are mainly Permo-Pennsylvanian and Cretaceous sediments. They form an isoclinal trough of which the axial plane strikes northwest and dips eastward. This larger structure was subjected to compression from the southwest and to tension acting in a northwesterly direction; shear complicated the structural pattern. The result is a fault mosaic. As a consequence, too, most of the productive veins trend about N. 40–80° E. The yielding that the stresses mentioned would seem to favor was, however, complicated by large plugs and sill-like in-

trusions of early Tertiary porphyry, not very greatly different from the typical "gray" porphyries of Alma, Leadville, and Gilman, Colorado; these plugs were also genetically connected with mineralization. The fact that most of the ore-bearing fissures are in the early Tertiary monzonite and quartz monzonite porphyries and in the Dakota quartzite is largely due to the competence of these rock varieties and the consequent development of open fissures.

Fissure veins are the dominant forms assumed by the ore bodies. The region is one of Paleozoic and Mesozoic overlap against the pre-Cambrian, and hence the Ordovician, Devonian, and Mississippian limestones that characterize other near-by mining districts, such as Alma, Aspen, and Leadville, are absent. Hence, in turn, blanket deposits like those at the camps just mentioned do not attain the prominence at Breckenridge that they possess elsewhere in this part of Colorado.

Much interest attaches also to the writer's revision of Ransome's statement respecting the importance of secondary sulphide enrichment of lead. Whereas in the earlier report a large part of the galena was regarded as resulting from secondary concentration, Lovering concludes, conservatively:—"Most of the lead was reprecipitated as cerussite," although he adds:—"Some secondary galena may have formed." This interpretation is more nearly in agreement with the observations of geologists in other western mining districts where similar geologic conditions prevail. Indeed, Lovering's discussion suggests that there is no conclusive evidence for the presence of even moderate amounts of secondarily concentrated galena, and his reasons for accepting any such galena are mainly deduced from probability, based on chemical considerations.

Of special significance in this economic report is the section entitled "Guides to Ore and Future of the District." What is offered under this heading is clearly and tersely stated and represents, from a practical viewpoint, the most useful section of the report. In view of the importance of this subject and the excellency of its treatment, the reviewer may be pardoned for wishing that this phase of the publication had been further expanded.

The volume carries two good geologic maps of the district, one of which shows the general geology, the other the fissures, faults, and veins. There is a series of structure sections, and there are numerous maps and sections of individual mines. All in all, the report is excellent in bringing up-to-date our understanding of an interesting district and in focussing generalizations based on the broader regional features upon the problems of ore deposition in a limited area.

CHAS. H. BEHRE, JR.

NORTHWESTERN UNIVERSITY,
EVANSTON, ILLINOIS.

Roman Mines in Europe. By OLIVER DAVIES. Pp. xii + 291, figs. 49, maps 6. Clarendon Press, Oxford, 1935. Price, $10.00.

The author has given in this volume a systematic description of the mines in the European provinces of the Roman Empire, so far as they can be identified, and brief statements of the nature of their ores and the methods of mining as described in the scanty available literature. Much of the material is the result of personal observation.

The book begins with a general discussion of the legal status of mining under the Roman law, its economic aspects, the conditions under which miners worked, and a rather full description of their tools and mining and metallurgical methods.

The special portion of the volume is devoted to the description of the recognized mines and quarries in Italy, Gaul, Spain, British Isles, Rhineland and the Upper Danube provinces, the Illyrian provinces, Dacia, Moesia, Macedonia and Thrace, and Greece. In each case the author's statements, when not the result of his personal observation, are founded on the ancient publications which he cites in detail and in great abundance. There are two indices, one of subject matter and the other of place names.

The volume should be of great value, not only to archaeologists and students of the economic history of the Roman Empire, but also to the student of the history of mining.

W. S. BAYLEY.

Erzlagerstätten. By H. SCHNEIDERHÖHN. Handwörterbuch der Naturwissenschaften, Auflage II, Band 3, pp. 844–882, 1933.

It is said of the geologist Werner that he bought books rather to arrange them systematically than to read them. The desire to arrange or classify objects and phenomena is not uncommon and where applied to natural phenomena it unquestionably has been of great value to science. The value of a good classification of ore deposits is that it gives the student an instrument for advancing the known horizon, it stimulates further work, and gives an orderly perspective on present-day knowledge.

In reports on government surveys or those made to companies utilizing mineral resources the classification adopted usually stresses the well-known easily demonstrable facts. Classifications based on metal or mineral content, form, character of wall rock and similar features result. Although such classifications are necessary, something more is essential in a classification that embraces the whole subject as a science. With the known facts, some theory must be interwoven, a process requiring skill, experience, and most of all, judgment. Finally the classification adopted must have pigeonholes or divisions adequately enough defined so that a considerable proportion of the known mineral deposits can with some confidence be assigned to its separate divisions.

The present classification has too much theory mixed with too little fact. Too much of it is based on special theories of geological processes, and divisions are made where the data or facts necessary for classification are not only not known, but can not at present be determined.

The deposits are first divided into four main groups:—(*A*) Deposits of magmatic origin, (*B*) Deposits of sedimentary origin, (*C*) Deposits of metamorphic origin, (*D*) Topomineralogic reaction deposits. This latter is supplementary to the first three divisions. The first group (*A*)—those of magmatic affiliations—is further subdivided into (α) Intrusive magmatic, (β) Extrusive magmatic. Under (α) are the following: I. Liquid magmatic; I-*a*. Liquid magmatic-pneumatolitic:—(1) Intramagmatic, (2) Ore injections; II. Pneumatolitic; II-*a*. Pneumatolitic-hydrothermal; III. Hydrothermal.

It would be interesting to have a dozen competent geologists independently pigeonhole a number of ore deposits in this group. Twelve different results might be expected, since classifying would be guessing with little or no basis of known fact. Those physical chemists most competent to know disagree on the state of the solutions formed toward and at the close of igneous rock crystallization, but to classify mineral deposits properly in these groups requires even more—a knowledge of the state of the solutions at the time of mineral formation. As a challenge to further investigation these proposed divisions may well have value, but as a means of giving a perspective on the present-day knowledge of these deposits, they leave much to be desired. Group (β) I, the deposits of extrusive magmatic origin, includes those formed by superficial volcanic activity. Examples mentioned are many of the Transylvania gold deposits, Hauraki, New Zealand; Comstock Lode and Tonopah, Nev.; Cripple Creek, Colorado; the copper deposits at Braden, Chile; cinnabar deposits as at Almaden, Spain, and Terlingua, Texas; many antimony deposits, and others.

To the reviewer this represents merely very interesting speculation, as applied to some of the examples. Some examples, however, require an origin of solutions much deeper than superficial. Some may be of superficial origin, but from the nature of the deposits, igneous rocks being at times lacking, particularly with cinnabar and stibnite deposits, the locus of solution origin is in most cases very speculative. Group (β) II comprises exhalations of fumarole type and submarine exhalations. The latter are said to account for iron ores of the Lahn syncline, Germany, and part of the "iron formations" of the Lake Superior Region,—both controversial questions.

Deposits of sedimentary origin (division (*B*)) is a designation used in a very broad inclusive way. It includes the products formed in the oxidation and supergene sulphide zones of sulphide ore bodies; kaolin

and bauxite deposits, carnotite deposits, also the well-known sedimentary iron ores. Within this division are also the deposits formed by descending meteoric waters. Examples mentioned include certain strontianite, iron and lead-zinc deposits. The logic of including these diverse types under "sedimentary" receives attention, but the average reader will probably find some difficulty in appreciating the new viewpoint or definition.

The third large division (*C*), deposits of metamorphic origin, mostly relates to mineral deposits that have been metamorphosed. The Alpine "cleft" minerals furnish, however, according to the author, one example of mineralization caused by metamorphism.

The final supplementary division includes the "topomineralogic reaction deposits," which contain new minerals and an unusual paragenesis formed by the reaction of mineralizing solutions with wall rock. Examples are: Lake Superior copper deposits, the silver deposits at Kongsberg, Norway, and the copper deposits at Engels, California. Regardless of how far one follows the views of B. S. Butler on wall-rock alteration, there are certainly many mineral deposits in which there is *some* dependence of certain alteration products, "reaction minerals," on the composition of host rock. How many of these should be included? Should deposits containing pyrrhotite replacing pyrite, or hematite replacing magnetite, etc., be placed in this division?

The final impression is that the classification contains many stimulating ideas, most of which are not new and have been discussed in more detail elsewhere. To the geologist of academic leanings the classification will undoubtedly have interest, since it draws together a number of the very interesting hypotheses regarding ore deposition and gives them a special emphasis.

W. H. NEWHOUSE.

MASS. INST. OF TECHNOLOGY,
CAMBRIDGE, MASS.,
Sept. 6, 1935.

BOOKS RECEIVED.

Petroleum Investigation, Pt. II. Pp. 869–1390, figs. 131. Hearings before a Subcommittee, Committee on Interstate and Foreign Commerce, House of Representatives, Washington, 1934. Contains: Geology and Occurrence of Petroleum in the United States, by U. S. Geological Survey, pp. 869–1086; Petroleum Development and Production, by H. C. MILLER AND B. E. LINDSLY, pp. 1087–1306; Effect of Technologic Factors on Supply of and Demand for Petroleum Products, by A. J. KRAEMER, pp. 1307–1390.

Contributions to the Data on Theoretical Metallurgy. IV, Metal Carbonates—Correlations and Applications of Thermodynamic Properties. K. K. KELLEY AND C. T. ANDERSON. Pp. 73. U. S. Bureau of Mines Bull. 384, Washington, 1935. 10 cts.

The Willow Creek-Kashwitna District, Alaska. S. R. CAPPS AND RALPH TUCK. Pp. 113, figs. 2. U. S. Geol. Survey Bull. 864–B. Washington, 1935. 5 cts.

Geology and Ground-Water Resources of the Island of Oahu, Hawaii. H. T. STEARNS AND K. N. VAKSVIK. Pp. xx + 479, pls. 33, figs. 34. Div. of Hydrography, Dept. of Public Lands, Terr. of Hawaii, Bull. 1. Prepared in co-operation with the U. S. Geological Survey. Honolulu, T. H., 1935.

The Physiography (Geomorphology) of Western Australia, 2d ed. J. T. JUTSON. Pp. xv + 366, figs. 147, pls. 5 (maps). Geol. Survey of Western Australia, Bull. 95. Perth, 1934. Revision of Bull. 61 (1914); thoroughly revised, and many portions entirely rewritten; much emphasis is placed on origin, especially in the Salinaland district, which includes the greater portion of the arid part of the State.

Les Ressources Minerales de la France d'outre-Mer. III. Le Zinc, le Plomb, l'Argent, le Cuivre, l'Or, les Minerais Radio-actifs, le Mica, les Pierres Précieuses, Substances Diverses. F. BLONDEL ET AL. Pp. 394, figs. 27, pls. 5. **IV. Le Phosphate.** L. CAYEUX, E. LENHARDT. Pp. 199, figs. 20, pls. 3. Bur. d'Etudes Geol. et Min. Coloniales. Paris, 1935.

Geologic History of the Vicksburg National Military Park Area. W. C. MORSE. Pp. 20, figs. 6, map. Mississippi State Geol. Survey Bull. 28. University, Miss., 1935.

Resumo da Geologia do Estado de Minas Gerais. O. BARBOSA AND D. GUIMARÃES. Pp. 40, map (in folder), scale 1:1,000,000. Dept. Serv. Geogr. e Geol., Serv. Geol. Bull. 3. Belo Horizonte, 1934.

A Study of Clay Winning and Its Costs in the Provinces of Ontario and Quebec. J. F. MCMAHON. Pp. 90, pls. 19, extensive bibliography. Canada Dept. of Mines, Mines Br. 754, Ottawa, 1935. 25 cts.

Portland Canal Area, British Columbia. GEO. HANSON. Pp. 179, figs. 17, maps 2. Canada Dept. of Mines, Bur. Econ. Geol. Memoir 175. Ottawa, 1935. 50 cts.

Lake Ainslie Map-area, N. S. G. W. H. NORMAN. Pp. 103, pls. 4, maps 2. Canada Dept. of Mines, Bur. Econ. Geol. Memoir 177. Ottawa, 1935. 25 cts.

The Mining Industry of Yukon, 1934. H. S. BOSTOCK. Pp. 10. Canada Dept. of Mines, Bur. Econ. Geol. Mem. 178. Ottawa, 1935. 10 cts.

Mudjatik-Haultain Area, Saskatchewan. F. J. ALCOCK. Pp. 16, figs. 1, pls. 2, maps 4. Canada Dept. of Mines, Bur. Econ. Geol. Memoir 180. Ottawa, 1935. 10 cts.

SCIENTIFIC NOTES AND NEWS

E. L. Bruce, who spent the summer in the Sturgeon River area, north of Lake Superior, has returned to Queen's University, Kingston, Canada.

T. W. Stanton, who has been a member of the U. S. Geological Survey staff since 1899, and for thirty years in charge of paleontology and stratigraphy, has retired as chief geologist.

G. F. Loughlin, of the U. S. Geological Survey, was promoted on October 1st from geologist in charge of Section of Metalliferous Deposits, to chief geologist.

Major B. Lightfoot, Director of the Southern Rhodesia Geological Survey, is visiting the United States under the auspices of the Carnegie Corporation in order to study the organization of geological survey work.

William D. Mark, head of the geological department of the Cerro de Pasco Copper Corporation, has resigned and is for the present at Wallace, Idaho.

Ellsworth Y. Dougherty is connected with Ventures, Ltd., Canadian operating and exploration company, with office at 25 King St., Toronto, Canada.

Charles Camsell, deputy minister of mines of Canada, has been on a 4,000-mile aerial tour through northern British Columbia and Northwest Territories to inspect government geological work.

Mark C. Malamphy, I. C. do Amaral and D. S. Oddone have been making a geophysical survey of three prospective gold mines in the vicinity of Curityba, Parana, Brazil. Their reports are to be published by the Government.

L. C. Graton, of Harvard University, has lately returned from a combined geological and fishing trip to South America.

J. T. Singewald, Jr., of Johns Hopkins University, has been on a 9,000-mile motor trip to Mexico, where he visited Pachuca, Tampico, Mexico City, Acapulco, and several silver mines near Tasco.

John T. Lonsdale has left the staff of the Agricultural and Mechanical College of Texas to join the faculty of the department of geology, Iowa State College, Ames, Iowa.

Frank D. Adams, McGill University, Montreal, recently represented the Geological Survey of Canada and the Royal Society of Canada at the centenary celebration of the Geological Survey of Great Britain in London.

J. W. Peoples, geologist for the Philadelphia & Reading Coal and Iron Co., has resigned to become assistant professor of geology at Wesleyan University, Middletown, Conn.

J. W. Vanderwilt, formerly of Golden, Colorado, has now opened an office at 527 Birch St., Denver.

FREDERICK LESLIE RANSOME,

1868–1935.

A MEMORIAL.

The first number of ECONOMIC GEOLOGY, issued in 1905, contains on its title page a list of Associate Editors and among them is the name of *Frederick Leslie Ransome;* and every number since then during these thirty years records the same name. Almost every one of these thirty volumes contains papers, discussions, editorials and reviews from his pen. With the deepest sorrow the editors have to announce the death of Ransome on October 6 of this year. He passed away the victim of an insidious disease and the end came as a great shock to his friends and admirers. They appreciated him as a man of the most sterling qualities; an eminent geologist known all over the world; a great investigator of ore deposits and other branches of economic geology.

Ransome was born in Greenwich, England, December 8, 1868, but received his technical education at the University of California under A. C. Lawson, obtaining his Ph.D. degree in 1896. Assistant Geologist and Geologist on the U. S. Geological Survey, 1897–1924; head of Geological Department, University of Arizona, 1924–1927; Professor of Economic Geology at the California Institute of Technology at Pasadena since 1927; Consulting Engineer for the Metropolitan Water District of Southern California since 1929; member of many scientific societies; former president of the Society of Economic Geologists and of the Washington Academy of Sciences; Treasurer of the National Academy of Science, 1919–1924. He has published about 100 papers and books, mainly on economic geology, the first (on the geology of the Coast Ranges) in 1893, the last (a historical review of geology as related to western mines) in 1933.

Although Ransome published many papers on mineralogy, physiography and engineering geology, his pre-eminent work was in field geology and petrography. He was a field geologist of great ability, as shown by the list of classical professional papers on Globe, Bisbee, Ray, Miami, all in Arizona; Cripple Creek, Colorado; Goldfield, Nevada, and Coeur d'Alene, Idaho; and his earlier folio on the Mother Lode, California. He also wrote many reports on smaller districts, which appeared in the publications of the U. S. Geological Survey. Furthermore, he wrote valuable papers on faulting and structure. His last years, since 1927, were mainly devoted to a study of high dams and water supply, partly in relation to the Boulder (Hoover) dam project. He was an exact observer and had wonderful ability to decipher geological structure; and as a rule was more interested in the exact recording of these observations than in advancing new theories without the firmest foundations.

All of us who tried to keep pace with him on the hillsides of Cripple Creek and elsewhere admired his sturdy physique and his long stride. No less did we admire him as a master of clear and logical English. Indeed, we trembled in our boots when, as often happened, our manuscripts were submitted to him for critical reading. We appreciated highly his professional ability and his keen, well-balanced, sane mind, not easily ruffled or disturbed.

We all feel, like his devoted family, that we have suffered an irreparable loss. We admired him perhaps most when, in plain view of death, he calmly wrapped his mantle around him and prepared for it.

WALDEMAR LINDGREN.